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SIMPLIFIED SPECTRAL FORECASTS OF SEA AND SWELL WAVES BY GRAPHICAL MEANS

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by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

United States Naval Postgraduate School
Monterey, California

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ABSTRACT

The spectral method of sea and swell wave forecasting yields more meaningful results than do other forecasting methods. To shorten the time required to make such a forecast the authors used high-speed computer methods and the Pierson-Neumann-James spectra to make spectral forecasts and display the results in graphic form for several synoptic weather models and a wide range of wind and fetch speeds. Forecasts were completed for a stationary fetch model, a fetch moving to leeward and a fetch moving to windward.

Computations were made with the assumptions that a rectangular generating area could be delineated; that a spatially-uniform mean wind existed; that this wind did not increase or decrease until the time of forecast; and finally that if the fetch were moving, its movement was steady.

The following parameter limits were established:

a. wind speeds, 15 to 55 knots;

b. speed of the generating area, 15 knots to and including the wind speed;

c. forecast times, 6 to 72 hours.

Results of the forecasts are plotted on approximately 250 graphs which show the geographic distribution of spectral sea or swell components relative to the fetch at forecast times.

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1. Introduction

It is universally understood that a need exists for a quick, yet accurate method for forecasting the wave conditions on the surface of the oceans of our planet. However it must be strongly emphasized that such a method should be spectral. It is important that the range of periods as well as heights of the waves be forecast. Some examples of where knowledge of wave periods is important are as follows:

(1) the emergency ditching of aircraft at sea,

(2) seaplane and aircraft carrier flight operations,

(3) refraction and shoaling of waves as they approach a shoreline,

(4) submarine surfacing and submergence.

This need for rapid spectral wave forecasting prompted the authors of this paper to perform the study and work herein discussed.

2. Background

Generally two catagories of forecast methods are available, a spectral method and a non-spectral method. The spectral forecast has the advantage of determining the range of periods with important energy but is a very tedious, time-consuming process. Furthermore, the technique requires that the forecaster be trained quite extensively. The non-spectral method has an advantage in that a forecast can be made rather rapidly and by a person with minimal training. However, it does not tell the user of the forecast the range of periods in which the wave energy lies.

Therefore, in order to permit accurate and more meaningful spectral forecasts by relatively untrained persons, high-speed computer methods were used to make spectral forecasts for as many synoptic weather models as time would permit and to display the results of the computer output in graphic form.

3. Basis of the Forecast Method

The Pierson-Neumann-James forecast method as outlined in H. O. Pub. No. 603 [3] was chosen as the basis for the wave forecasts. In order to avoid repeating a great volume of theory and methods, it will be assumed that the reader has a working knowledge of this publication. It is recognized that Pierson and Moskowitz [1 and 2] are developing new spectra which will improve upon the PNJ spectra now in widespread use. Therefore, the computer programs were written in such a manner as to allow utilization of these new spectra or others as they are published.

In making a forecast of sea and swell conditions, one must know at what location within the generating area and how long after the wind began to blow that waves of a given period are first formed. This information is gleaned from the Co-Cumulative Spectra. Then one must know the velocity with which the waves are propagated. Each spectral component moves at its respective group velocity, the direction being accounted for by an angular spreading function. When these characteristics have been determined, the distribution of wave periods over any geographical area can be shown graphically.

For each wind speed and fetch description considered, this distribution is shown for various times since the wind started blowing.

4. Synoptic Models Completed

To date, three models have been completed:

(1) a stationary fetch model which may be associated with a stationary cyclone, trough or ridge;

(2) a model with a fetch moving to leeward, as associated with the southern quadrant of a cyclone moving eastward;

(3) a model with a fetch moving to windward as associated with the northern quadrant of a cyclone moving eastward.

In the following sections the variables and equations associated with each model are discussed.

A discussion of the computer programming and procedures is found in Appendix A.

5. Stationary Fetch Model

5.1 FOPRIME

With this case a description of wave conditions within the generating area (SEA) must be given. In order to generate waves of a given period, the wind must blow over a minimum length of fetch for a sufficient time. This minimum distance, measured from the windward edge of the fetch, is given the name FOPRIME. The values for each period are determined from the CCS,

$$\text{FOPRIME} = F_o'(V, t_d) \tag{1}$$

where V is the wind velocity and t_d is the duration time. Graphs for specified velocities and various times of observation show plots of the highest period present versus FOPRIME. These graphs are also called FOPRIME. The use of these and all other graphs is explained in Section 10.

5.2 SWELL

A description of the waves emanating from the generating area (SWELL) in the general direction of the wind also must be given. As soon as a spectral component with period T_i is formed, it moves with a group velocity,

$$V_i = 1.515\ T_i(V, t_d) \tag{2}$$

where T_i, the period of the longest wave, is a function of wind velocity and duration. Assuming that all swell waves are propagated from the leeward edge of the fetch, their maximum distance from this edge at some observation time t_{ob} is:

$$\text{SWELL} = (t_{ob} - t_d)V_i \tag{3}$$

Graphs of spectral component versus SWELL for various observation times are also called SWELL.

6. Moving (leeward) Fetch Model

6.1 FOPRIME

For this synoptic model the description of the SEA conditions within the windward and leeward portions of the fetch must be given. Since the fetch is moving, it is assumed that the windward portion of the fetch is completely filled in with waves that have group velocities less than the fetch velocity. FOPRIME for each spectral component with group velocity greater than the fetch velocity is obtained from the CCS. The graphs showing the distribution of spectral components versus FOPRIME are called FOPRIME.

6.2 SUMDEL

Due to the movement of the fetch into an area where it is assumed calm seas exist, the effective duration of the wind blowing over the leeward portion of the fetch is less than for a stationary fetch. Therefore, the distance behind the leading edge of the fetch that a spectral component of period, T_i, can first be formed during an increment of duration time Δt_i is

$$\Delta D_i = (V_f - 1.515\ T_i)\ \Delta t_i \qquad (4)$$

where V_f is the fetch velocity. Each spectral component requires a specific generation time; a summation of the duration increments Δt_i determines this generation time, $t_d = \sum_{i=1}^{N} \Delta t_i$. The summation of ΔD's determines the total lag of that component behind the leading edge of the fetch; this distance is called SUMDEL.

$$\text{SUMDEL} = \sum_{i=1}^{N} \Delta D_i . \qquad (5)$$

If a spectral component generated at a particular time t_d has a group velocity greater than the fetch velocity, then at time t_{ob} this component has advanced relative to the leading edge of the fetch an amount,

$$\text{DIST} - (t_{ob} - t_d)\ V_f ,$$

where DIST is the travel distance of the component since it was generated and $(t_{ob}-t_d)\ V_f$ is the distance the fetch advances during this same period of time.

$$DIST = (t_{ob}-t_d)\ V_i \tag{6}$$

Hence SUMDEL is modified by this relative travel of the high-speed spectral component. The resulting distance that a specific spectral component lags behind the leading edge of the moving fetch at t_{ob} is called SWEDEL.

$$SWEDEL = SUMDEL - DIST + (t_{ob}-t_d)\ V_f. \tag{7}$$

6.3 SWELL

The distribution of the swell to leeward of the fetch is similar to that in the stationary fetch model, but since the fetch is moving it becomes necessary to consider the distance traveled by the leading edge since the generation of a specific spectral component, $(t_{ob}-t_d)\ V_f$, and SUMDEL, the distance behind the leading edge that a specific component is formed. Thus, in this case,

$$SWELL = (t_{ob}-t_d)\ V_i - (t_{ob}-t_d)\ V_f - SUMDEL. \tag{8}$$

Graphs showing the range of periods of the spectral components versus SWELL for various observation times are called SWELL.

6.4 LAG

As the fetch moves to leeward at a specific velocity, spectral components with group velocities lower than the fetch velocity fall out of the windward portion of the fetch, assuming as before that the windward part of the fetch is completely filled in by these spectral components. The distance that a wave component with period T_i lags behind the trailing edge of the fetch at t_{ob} is termed LAG, where

$$LAG = (t_{ob}-t_d)\ V_f - (t_{ob}-t_d)\ V_i, \tag{9}$$

or by rearranging terms

$$LAG = (t_{ob}-t_d)\ (V_f - V_i)\ . \qquad (10)$$

Graphs showing the distribution of spectral components versus LAG are called LAG.

7. Moving (windward) Fetch Model

For this situation only two of the areas previously mentioned need describing, the area within the fetch and the area behind the trailing edge where swell is found.

7.1 SUMDEL

The distance behind the leading edge of the fetch that a specific spectral component is first formed is called SUMDEL as defined by (5). Since the fetch movement and wind direction are opposite, (4) is modified to

$$\Delta D_i = (V_f + 1.515\ T_i)\ \Delta t_i. \tag{11}$$

The graphs describing the generating area in this case are called SUMDEL.

7.2 LAG

Immediately upon generation, waves of a given spectral component move out of the generating area. Their distance behind the trailing edge is called LAG. Because of the opposite directions of movement of fetch and wind, equation (10) becomes

$$LAG = (t_{ob} - t_d)(V_f + V_i). \tag{12}$$

The graphs depicting the location of spectral components behind the fetch at a specific observation time are called SWELL.

8. Definitions Used in the Forecast Method

To make clear the notations used in subsequent sections, the following terms are defined. Most terms are the same as those used in [3]. However, some of the terms are unique to this paper.

Fetch - That limited or bounded area of the ocean where it is assumed a mean steady wind is blowing and generating waves. The area is also assumed to be rectangular with one axis along the wind path. Also referred to as a generating area.

Sea - Those waves found within the generating area.

Swell - Those waves which have moved out of a generating area.

R_o - The distance from the center of the leeward edge of a generating area to the point P at which a forecast will be made.

L_o - The distance from the center of the windward edge of a moving (leeward) fetch to P, measured in a direction opposite to fetch motion.

T_U - The highest wave period in either a sea or swell. T_U is a function of wind speed and duration.

T_{FU} - The highest wave period in either a sea or swell where a relatively short fetch limits the growth of waves. Refer to section 13.1d.

T_L - The lowest period in either a sea or swell.

E_U - The energy in that part of the spectrum between the periods zero and T_U.

E_L - The energy in that part of the spectrum between the periods zero and T_L.

ΔE - The energy associated with that portion of the wave spectrum with periods from T_L to T_U. $\Delta E = E_U - E_L$.

θ_3, θ_4 - The angles between the direction of the mean wind and the lines drawn from P to the center of each side of the fetch.

S_θ - The angular spreading factor, determined by θ_3 and θ_4 from the Angular Spreading Factor Table, explained in Section 11.

ΔE_θ - The total increment of energy arriving at P at a specific time. This energy is a function of wind speed, fetch speed, distance from the fetch and the relative direction of P from the fetch. $\Delta E_\theta = \Delta E(S_\theta) = (E_U - E_L)\ (S_\theta)$

t_{ob} - The time of the forecast, measured from the time the wind began to blow (e. g. if the wind begins at 010000Z and a forecast at P is to be made for 020600Z then t_{ob} is 30 hours). Also referred to as observation time.

V - Mean wind speed in knots.

V_f - Mean fetch speed in knots.

9. Parameter Limits

The range of wind velocities considered for the computer computations was from 15 to 55 knots. Below 15 knots, the wave energy is considered insignificant. The upper limit of 55 knots is controlled by the fact that the PNJ spectra are given only up to 56 knots. Since facsimile weather maps show wind speeds in increments of five knots, this increment value was used for the computations.

The range of fetch velocities used was from 15 knots up to the existing wind velocity. It was considered unlikely that a delineated generating area would move faster than the wind velocity within it. For fetch velocities less than 15 knots, it was considered that the stationary fetch graphs could be used, assuming some mean location of the fetch.

Graphs to forecast sea and swell conditions were drawn for observation times from 6 to 72 hours. The upper limit was arbitrarily set by the authors. The observation time was incremented by six hours for convenience. Any other times can be found by interpolation.

For the moving-fetch models, a fetch-length limitation of 1600 nautical miles was established for reasonable graph scaling. This limitation seems reasonable since it is doubtful that a uniform wind field larger than this would be found. This fetch limitation is especially noticeable in limiting the formation of low-frequency waves in the Moving (windward) Fetch Model.

10. Use of Graphs

Each of the graphs discussed has 12 separate or superimposed curves showing the range of wave periods at geographic locations for observation times from t_{ob} = 6 hours to t_{ob} = 72 hours at six-hour intervals. Fig. 1 shows a time series of graphs approximating a situation where a generating area with a mean wind velocity of 35 knots (V = 35) moves across the ocean with a fetch velocity of 20 knots (V_f= 20). The final graph in each column is the composite picture where curves for all times are superimposed. The shaded areas in each case show the range of periods present at all locations. All distances measured on the graphs are relative to the windward or leeward edge of the fetch.

To make forecasts for times other than those of the observation time curves, the forecaster may interpolate between curves.

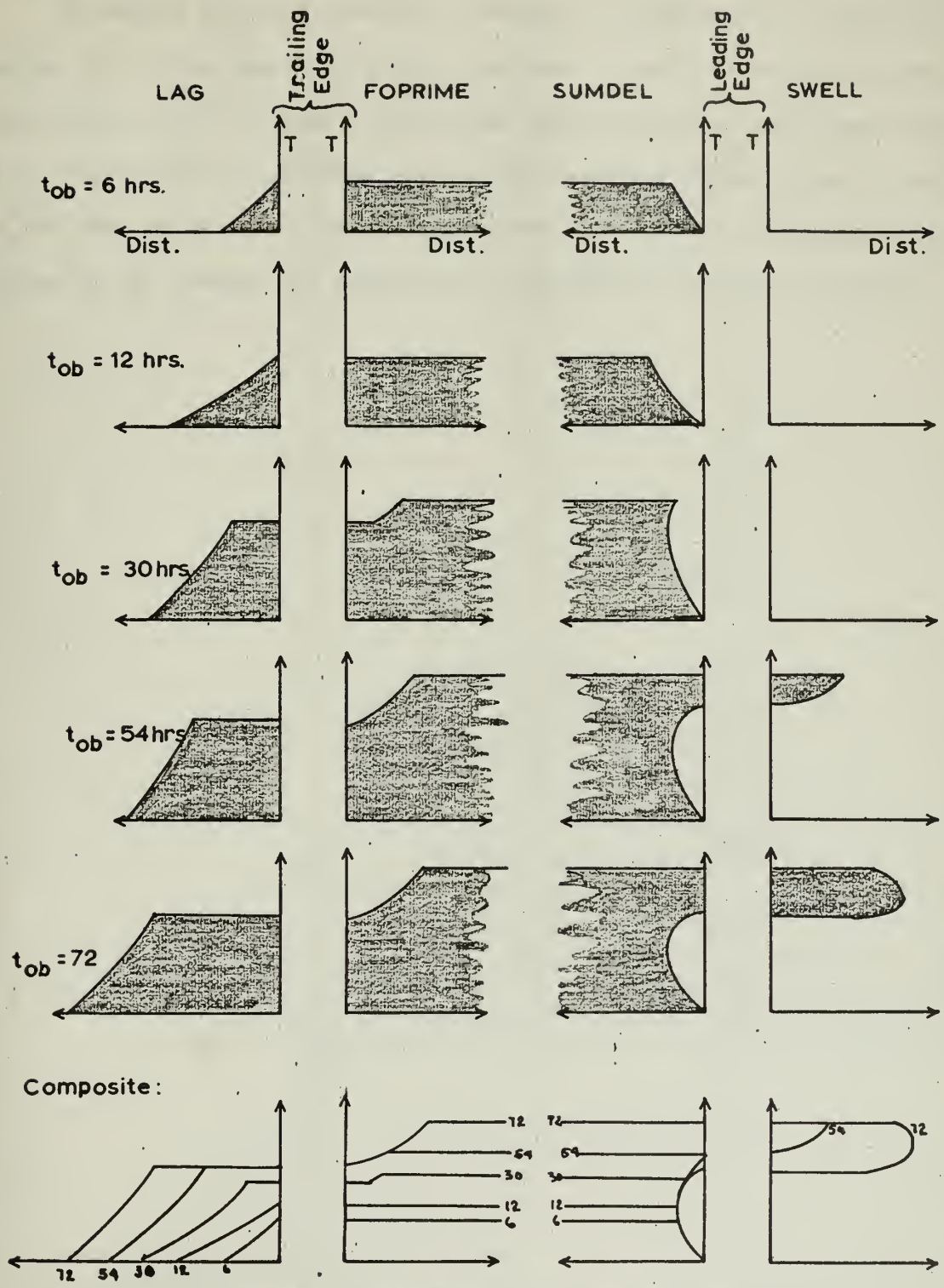


Figure 1. Time Series of Graphs Showing Distribution of Spectral Wave Components Relative to a Moving (leeward) Fetch.

11. Use of the Angular Spreading Table

The angles θ_3 and θ_4 defined in Section 8 determine the reduction of energy due to the angular spreading the waves undergo after leaving the generating area. The angular spreading factor nomograph in [3] was used to formulate Table 1, showing the angular spreading factor S_θ as a function of the two angles in ten-degree increments. It is felt that measuring these angles to the nearest ten degrees gives sufficiently accurate results.

θ_4 \ θ_3	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0	+10°	+20°	+30°	+40°	+50°	+60°	+70°	+80°
-80°	-	.01	.03	.07	.12	.20	.30	.40	.50	.60	.70	.80	.88	.93	.97	.99	1.0
-70°	.01	-	.02	.06	.11	.19	.29	.39	.49	.59	.69	.79	.87	.92	.96	.98	.99
-60°	.03	.02	-	.04	.09	.17	.27	.37	.47	.57	.67	.77	.85	.90	.94	.96	.97
-50°	.07	.06	.04	-	.05	.13	.23	.33	.43	.53	.63	.73	.81	.86	.90	.92	.93
-40°	.12	.11	.09	.05	-	.08	.18	.28	.38	.48	.58	.68	.76	.81	.85	.87	.88
-30°	.20	.19	.17	.13	.08	-	.10	.20	.30	.40	.50	.60	.68	.73	.77	.79	.80
-20°	.30	.29	.27	.23	.18	.10	-	.10	.20	.30	.40	.50	.58	.63	.67	.69	.70
-10°	.40	.39	.37	.33	.28	.20	.10	-	.10	.20	.30	.40	.48	.53	.57	.59	.60
0	.50	.49	.47	.43	.38	.30	.20	.10	-	.10	.20	.30	.38	.43	.47	.49	.50
+10°	.60	.59	.57	.53	.48	.40	.30	.20	.10	-	.10	.20	.28	.33	.37	.39	.40
+20°	.70	.69	.67	.63	.58	.50	.40	.30	.20	.10	-	.10	.18	.23	.27	.29	.30
+30°	.80	.79	.77	.73	.68	.60	.50	.40	.30	.20	.10	-	.08	.13	.17	.19	.20
+40°	.88	.87	.85	.81	.76	.68	.58	.48	.38	.28	.18	.08	-	.05	.09	.11	.12
+50°	.93	.92	.90	.86	.81	.73	.63	.53	.43	.33	.23	.13	.05	-	.04	.06	.07
+60°	.97	.96	.94	.90	.85	.77	.67	.57	.47	.37	.27	.17	.09	.04	-	.02	.03
+70°	.99	.98	.96	.92	.87	.79	.69	.59	.49	.39	.29	.19	.11	.06	.02	-	.01
+80°	1.0	.99	.97	.93	.88	.80	.70	.60	.50	.40	.30	.20	.12	.07	.03	.01	-

TABLE 1. ANGULAR SPREADING FACTOR

12. Use of the Energy Table

For a rapid forecast, measuring the range of wave periods to the nearest whole second at any given location seems sufficiently accurate. Hence the simplified Energy Table (Table 2) gives the energy associated with a spectrum of waves with periods from zero to T, listed on the left vertical edge of the table. Enter this table with V, and T_U or T_L to determine E_U or E_L respectively. For more accuracy, the period to the nearest tenth may be read from the graphs and the energy value from Table 2 interpolated. These extracted values have units, $feet^2$.

T (SEC) \ V (Kts)	15	20	25	30	35	40	45	50	55
4	.4	.7	.7	1.0	1.5	2.5	3.1	3.6	4.3
5	.7	1.6	2.2	2.9	3.5	4.2	5.0	5.6	5.9
6	1.1	3.0	4.4	5.1	6.0	7.8	8.8	10.0	11.0
7	1.4	3.9	6.1	8.3	9.5	12.0	15.0	17.5	20.0
8	1.7	5.0	9.3	14.5	17.5	22.0	24.0	28.0	32.0
9	1.9	5.8	12.5	21.0	26.5	32.0	37.0	43.0	47.0
10		6.2	16.0	29.0	40.0	50.0	65.0	70.0	74.0
11		7.0	17.5	34.5	50.0	68.0	86.0	95.0	100
12		7.7	20.	40.	64.	90.	107.	130.	145.
13			22.	45.	75.	110.	132.	170.	195.
14			24.	47.	86.	130.	168.	220.	255.
15				50.	96.	160.	210.	270.	315.
16				55.	106.	180.	255.	325.	400.
17				59.	112.	190.	285.	390.	450.
18					123.	205.	320.	450.	525.
19					128.	220.	350.	500.	620.
20						230.	375.	530.	700.
21						243.	410.	600.	770.
22						247.	420.	630.	820.
23							430.	660.	860.
24							450.	700.	900.
25								715.	
26								730.	

TABLE 2. ENERGY TABLE



13. Forecasting Procedures

The following is a concise, step-by-step procedure to be followed in making a forecast.

13.1 Preliminary steps

a. Draw the boundaries of the generating area on a synoptic weather chart; determine the mean wind, V, within the area and if the fetch is moving determine a mean fetch speed, V_f.

b. Locate the point of interest, P, where the forecast is to be made.

c. Determine into which of the synoptic models the forecast falls:

1. Stationary Fetch Model (Section 13.2)

2. Moving (leeward) Fetch Model (Section 13.3)

3. Moving (windward) Fetch Model (Section 13.4)

13.2 Stationary Fetch Model

A sea or swell forecast is made for P depending on the location relative to the fetch as shown in Fig. 2.

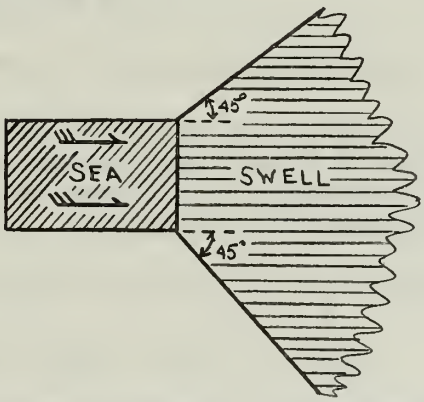


Figure 2. Sea and Swell Areas Associated with a Stationary Fetch

a. Sea Forecast

1. Measure the distance from P to the windward edge of the fetch.

2. Enter the FOPRIME graph for the appropriate windspeed with this distance and t_{ob} to obtain T_U.

3. Assume T_L is zero; therefore, E_L is zero.

4. From Table 2 determine E_U, a function of T_U and V.

5. Assume that within the generating area the angular spreading factor S_θ is unity; therefore, ΔE_θ equals E_U.

6. For characteristic wave height computation, refer to the formulae in Table 3.

b. Swell Forecast

(If P lies outside the sector outlined in Fig. 2, swell will be considered insignificant.) [See Note]

1. Determine as outlined below if the length of the fetch will limit the growth of waves (e.g., a 30-knot wind with a duration of 24 hours can produce waves with periods up to 16.7 seconds if the fetch length is at least 280 nautical miles. If the fetch length is only 200 NM, the highest period of wave which can be generated is 11.7 seconds). Enter the FOPRIME graph for the given V, V_f and t_{ob} with fetch length to determine the highest period of waves generated. If this period is less than the highest period on that t_{ob} curve, then it is called T_{FU} and replaces T_U in the remainder of the swell forecast. (See Example Forecast No. 1.)

2. Measure R_o.

3. Enter SWELL graph for appropriate V and t_{ob} and obtain T_U (or T_{FU}) and T_L.

4. From Table 2 determine E_U and E_L.

5. Draw lines from P to the centers of the sides of the generating area and measure angles θ_3 and θ_4 as shown in Fig. 6. Angles are negative if measured clockwise from the wind direction, and positive if measured counterclockwise.

6. Enter Table 1 with θ_3 and θ_4 and determine S_θ.

7. Calculate $\Delta E_\theta = (E_U - E_L)\ (S_\theta)$

8. Use formulae in Table 3 to determine wave heights.

13.3 Moving (leeward) Fetch Model

Fig. 3 is an aid in determining the type of waves to be forecast. Prior to any other steps the fetch must be tracked ahead to its location at the time of forecast, t_{ob}.

Note: When a long generating area exists, swell may emanate from the sides of the fetch. In such cases, the 45°-sectors shown on Fig. 2 may be moved toward the windward edge of the fetch an amount deemed necessary by the forecaster.

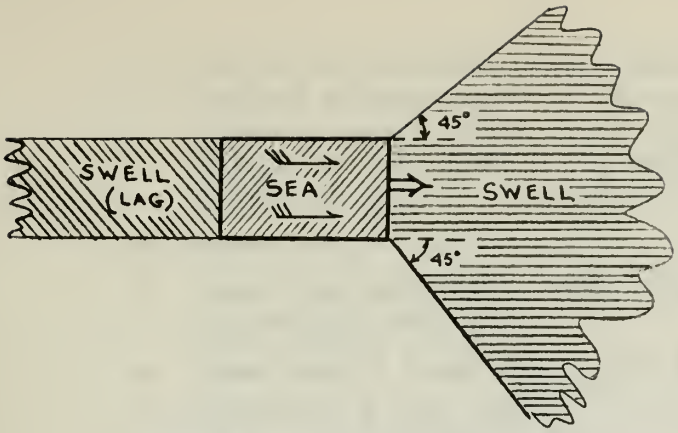


Figure 3. Sea and Swell Areas Associated with a Moving (leeward) Fetch.

a. Sea Forecast

(Since the graphs are drawn to cover a wide range of conditions, the highest period of sea waves may be determined from either the FOPRIME or SUMDEL graph. Generally, for slow fetch speeds T_U will be determined from the FOPRIME graph and for high fetch speeds T_U will be determined from the SUMDEL graph; therefore, both graphs should be investigated.)

1. Measure the distance from P to the trailing edge of the fetch.
2. Enter the appropriate FOPRIME graph with this distance and t_{ob} to obtain T_U.
3. Measure the distance from P to the leading edge of the fetch.
4. Enter the appropriate SUMDEL graph with this distance and t_{ob} to obtain T_U. If two separate bands of wave periods are in evidence, assume all periods between zero and T_U are present.
5. Using the smaller of the two values of T_U obtained in steps 2 and 4, enter Table 2 and obtain E_U.
6. Assume T_L is zero; therefore, E_L is zero.
7. Assume $S_\theta = 1$; therefore $\Delta E_\theta = E_U$.
8. Use the formulae in Table 3 to determine wave heights.

b. Swell Forecast for Area Leeward of the Fetch

(Swell is present ahead of the generating area only in the sector shown on Fig. 3 and only if the fetch is moving at speeds of 20 knots or less.)

1. As in the Stationary Fetch Model forecast (Section 13.2b), it must be determined if the fetch length limits the generation of waves. With fetch length enter the FOPRIME and SUMDEL graphs for the given V, V_f and t_{ob} to determine T_{FU} from each graph and select the lower of these values.
2. Measure R_o.
3. Enter the appropriate SWELL graph with R_o and t_{ob} to obtain T_U (or T_{FU}) and T_L.
4. From Table 2 determine E_U and E_L.
5. Determine θ_3, θ_4 and S_θ.
6. Calculate $\Delta E_\theta = (E_U - E_L)\ (S_\theta)$.
7. Use formulae in Table 3 to determine wave heights.

c. Swell Forecast for Area Windward of the Fetch

1. Measure L_o.
2. Enter the appropriate LAG graph with L_o and t_{ob} to obtain T_U.
3. Assume T_L is zero; therefore, E_L is zero.
4. From Table 2 determine E_U.
5. Since it is difficult to determine an angular spreading factor for swell waves traveling slower than the fetch, assume $S_\theta = 1.0$ and hence the swell heights are the maximum possible for this area. Hence, $\Delta E_\theta = E_U$.
6. Refer to Table 3 for height computations.

13.4 Moving (windward) Fetch Model

Fig. 4 describes the location of swell relative to the generating area. Prior to any forecasting steps the fetch must be tracked ahead to its location at t_{ob}.

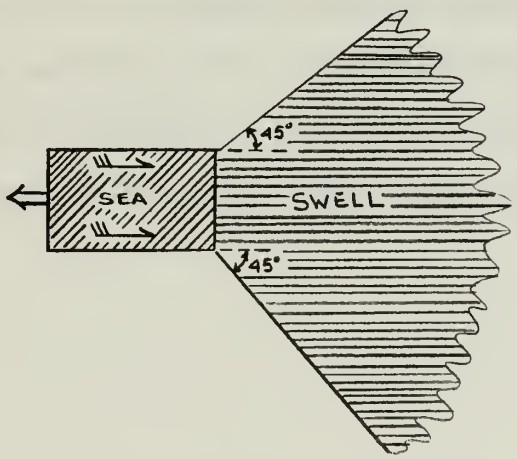


Figure 4. Sea and Swell Areas Associated with a Moving (windward) Fetch.

a. Sea Forecast

1. Measure the distance from P to the leading edge of the fetch.

2. Enter the appropriate SUMDEL graph with this distance and t_{ob} to determine T_U.

3. From Table 2 determine E_U.

4. Assume T_L is zero; therefore E_L is zero.

5. Assume $S_\theta = 1.0$; therefore, $\Delta E_\theta = E_U$.

6. Refer to Table 3 for height computations.

b. Swell Forecast

1. Determine if the fetch length limits the growth of waves by entering the appropriate SUMDEL graph with fetch length and t_{ob} as in Section 13.2b.

2. Measure R_o.

3. Enter the appropriate SWELL graph with R_o and t_{ob} to obtain T_U (or T_{FU}) and T_L.

4. From Table 2 determine E_U and E_L.

5. Measure θ_3 and θ_4 and obtain S_θ from Table 1.

6. Calculate $\Delta E_\theta = (E_U - E_L)(S_\theta)$.

7. Refer to Table 3 for height computations.

13.5 Multiple Storms

Should it appear that the forecast location might be under the influence of more than one storm, the increments of energy, ΔE_θ, at P from each storm should be calculated individually and then summed. Height characteristics are computed from this summed energy increment.

14. Wave Heights

The following formulae used most often are the same as those appearing in [3]; they have been modified only to agree with the symbols used in this paper. For determining range of heights, exceptionally high waves, and amplitude information, refer to [3], Chapter I.

Table 3. Wave Heights.

Most frequent height	$H_{freq} = 1.41\sqrt{\Delta E_\theta}$
Average wave height.	$H_{ave} = 1.77\sqrt{\Delta E_\theta}$
Significant wave height (highest 1/3). .	$H_{1/3} = 2.83\sqrt{\Delta E_\theta}$
Average height of highest 1/10	$H_{1/10} = 3.60\sqrt{\Delta E_\theta}$

15. Forecast Worksheet

In order to systematize the described processes, a worksheet (Fig. 5) was devised. The blanks provided are filled with information extracted from the graphs and tables of the system. It is recommended that any unit using the forecast method reproduce this worksheet. The completed worksheet may be kept on file to provide a permanent record.

Sea and Swell Forecast Worksheet

Forecaster: _____ Location: _____(Lat.)_____(Long.) Time: _____Z t_{ob}: __ hrs. Approved: _____

V: _____ V_f: _____ Fetch Length: _____

STATIONARY FETCH

SEA:

Dist. P to Wind. Edge: _____

T_U: _____, $E_U = \Delta E_\Theta$: _____

$H_{1/3}$: _____

SWELL:

R_O: _____

T_U: _____, E_U: _____

T_L: _____, E_L: _____

Θ_3: _____, Θ_4: _____, S_Θ: _____

$\Delta E_\Theta = (E_U - E_L)(S_\Theta)$: _____

$H_{1/3}$: _____

MOVING (LEEWARD) FETCH

SEA:

Dist. P from Trailing Edge: _____

Dist. P to Leading Edge: _____

T_U: _____, $E_U = \Delta E_\Theta$: _____

$H_{1/3}$: _____

SWELL:

R_O: _____

T_U: _____, E_U: _____

T_L: _____, E_L: _____

Θ_3: _____, Θ_4: _____, S_Θ: _____

$\Delta E_\Theta = (E_U - E_L)(S_\Theta)$: _____

$H_{1/3}$: _____

LAG:

L_O: _____

T_U: _____, $E_U = \Delta E_\Theta$: _____

$H_{1/3}$: _____

MOVING (WINDWARD) FETCH

SEA:

Dist P to Leading Edge: _____

T_U: _____, $E_U = \Delta E_\Theta$: _____

$H_{1/3}$: _____

SWELL:

R_O: _____

T_U: _____, E_U: _____

T_L: _____, E_L: _____

Θ_3: _____, Θ_4: _____, S_Θ: _____

$\Delta E_\Theta = (E_U - E_L)(S_\Theta)$: _____

$H_{1/3}$: _____

Figure 5. Sea and Swell Forecast Worksheet.

16. Example Forecasts

Example forecasts, made for three synoptic fetch models, are organized in the format of Section 13 (Forecasting Procedures) with correspondingly numbered steps. Each step is amplified by reference to a figure or table from which the information is obtained.

16.1 Example Forecast No. 1: Stationary Fetch Model

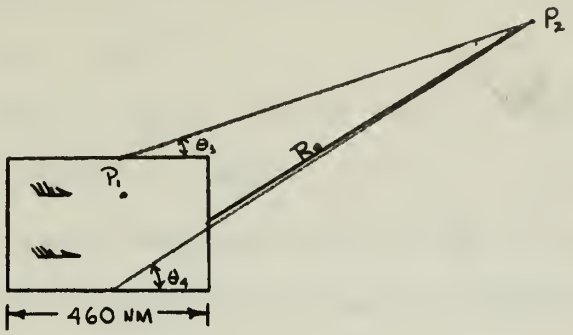


Figure 6. Geographic Positions of P_1 and P_2 Relative to a Stationary Fetch.

Fig. 6 portrays a fetch located in one geographic position for a period of at least 60 hours. From the synoptic and prognostic weather charts and Fig. 6 the following preliminary information is obtained for the forecast:

1. the positions of P_1 and P_2;
2. V = 35 knots beginning at 192100Z;
3. a Stationary Fetch Model.

Proceeding with the steps as outlined in Section 13.2:

a. Sea Forecast for P_1 at 220000Z; t_{ob} = 60 hrs.

1. Distance from the windward edge to P_1 = 275 NM
2. T_U = 12 sec. (FOPRIME graph; Fig. 7)
3. T_L = 0; E_L = 0.
4. E_U = 64.0 (Table 2)
5. ΔE_θ = 64.0
6. $H_{1/3} = 2.83\sqrt{64} = 2.83(8) = 22.6$ ft. (Table 3)

b. Swell Forecast for P_2 at 220000Z; t_{ob} = 60 hrs.

1. No fetch limitation on highest period generated. (See Note 1)
2. R_o = 700NM (Fig. 6)
3. T_U = 19; T_L = 12 (SWELL graph: Fig. 8)

4. $E_U = 128$; $E_L = 64$ (Table 2)

5. $\theta_3 = +20^\circ$; $\theta_4 = +40^\circ$ (Fig. 6)

6. $S_\theta = .18$ (Table 1)

7. $\Delta E_\theta = (E_U - E_L)(S_\theta) = (128-64)(.18) = 64(.18) = 11.5$

8. $H_{1/3} = 2.83\sqrt{11.5} = 2.83(3.4) = 9.6$ ft. (Table 3)

Note 1: If the fetch length were only 400 NM the building of waves would be limited so that T_{FU} would be 16 seconds (FOPRIME graph: Fig. 7). Then $T_U = T_{FU} = 16$ seconds at P_2 and $H_{1/3} = 7.6$ ft.

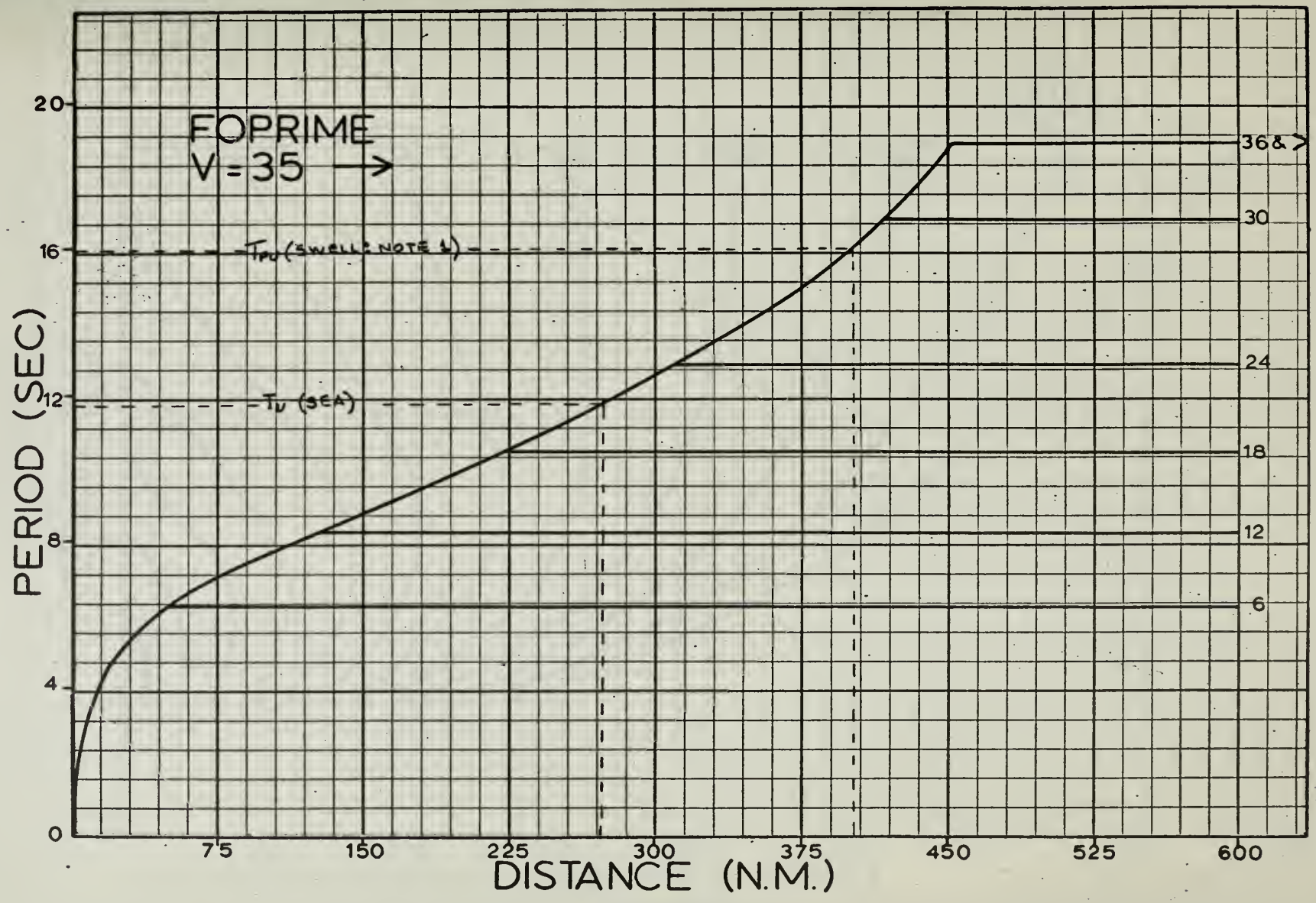

FOPRIME
V=35 →
T_{PD} (SWELL: NOTE 4)
T_V (SEA)
PERIOD (SEC)
0
4
8
12
16
20
75
150
225
300
375
450
525
600
DISTANCE (N.M.)
6
12
18
24
30
36 &

Figure 7.



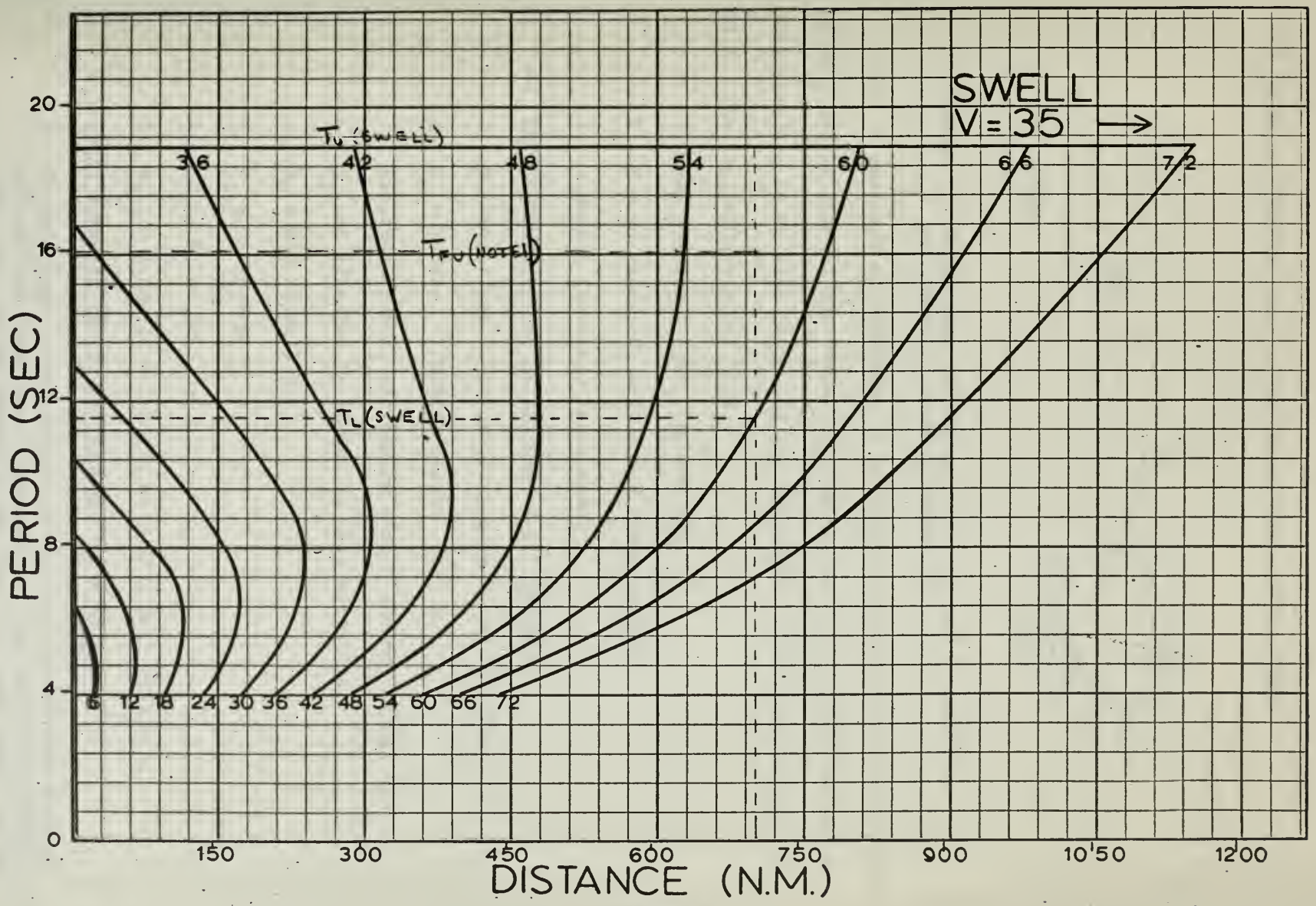

SWELL
V = 35 →
T_U (SWELL)
T_{FU} (HOTEL)
T_L (SWELL)
36
42
48
54
60
66
72
6 12 18 24 30 36 42 48 54 60 66 72
PERIOD (SEC)
0
4
8
12
16
20
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

Figure 8.



16.2 Example Forecast No. 2: Moving (leeward) Fetch Model

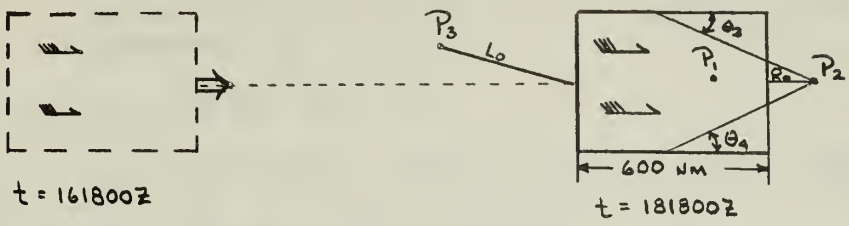


Figure 9. Geographic Positions of P_1, P_2 and P_3 Relative to a Moving (leeward) Fetch.

Fig. 9 portrays the movement of a fetch from the time the wind began blowing to the time of the forecast, showing the three points for which forecasts are to be made following the procedure as outlined in Section 13.3. The preliminary steps show:

1. the positions of P_1, P_2 and P_3;
2. V = 40 knots; V_f = 15 knots since 161800Z;
3. a Moving (leeward) Fetch Model.

a. Sea Forecast for P_1 at 181800Z: t_{ob} = 48 hrs.

1. Distance from P_1 to trailing edge = 450 NM (Fig. 9)
2. T_U = 14 sec. (FOPRIME graph: Fig. 10)
3. Distance from P_1 to leading edge = 150 NM (Fig. 9)
4. P_1 not affected by SUMDEL in this situation.
5. E_U = 130 (Table 2)
6. T_L = 0; E_L = 0
7. $\Delta E_\theta = E_U$ = 130
8. $H_{1/3} = 2.83\sqrt{130} = 2.83(11.4) = 32.2$ ft. (Table 3)

b. Swell Forecast for P_2 at 181800Z: t_{ob} = 48 hrs.

1. To determine if the length of the fetch limits the highest wave period which can be generated enter both the FOPRIME graph (Fig. 10) and the SUMDEL graph (Fig. 11) with fetch length and obtain:

T_{FU} = 18 sec. (FOPRIME graph)

T_{FU} = 22 sec. (SUMDEL graph)

Using the smaller of the two, the highest possible wave period generated, T_{FU} = 18 sec.

2. R_o = 100 NM (Fig. 9)

3. $T_U = T_{FU}$ = 18 sec. (Step 1) ; T_L = 14 sec. (SWELL graph: Fig. 12)

4. E_U = 205; E_L = 130. (Table 2)

5. $\theta_3 = +30^o$; $\theta_4 = -30^o$; S_0 = .6 (Fig. 9 and Table 1)

6. ΔE_θ = (205-130) (.6) = 45.0

7. $H_{1/3} = 2.83\sqrt{45}$ = 19 ft. (Table 3)

c. Swell Forecast for P_3 at 181800Z: t_{ob} = 48 hrs.

1. L_o = 400 NM (Fig. 9)

2. T_U = 6 sec. (LAG graph: Fig. 13)

3. $T_L = 0$; $E_L = 0$.

4. E_U = 7.8 (Table 2)

5. $E_\theta = E_U$ = 7.8

6. $H_{1/3} = 2.83\sqrt{7.8}$ = 7.9 ft. (Table 3)

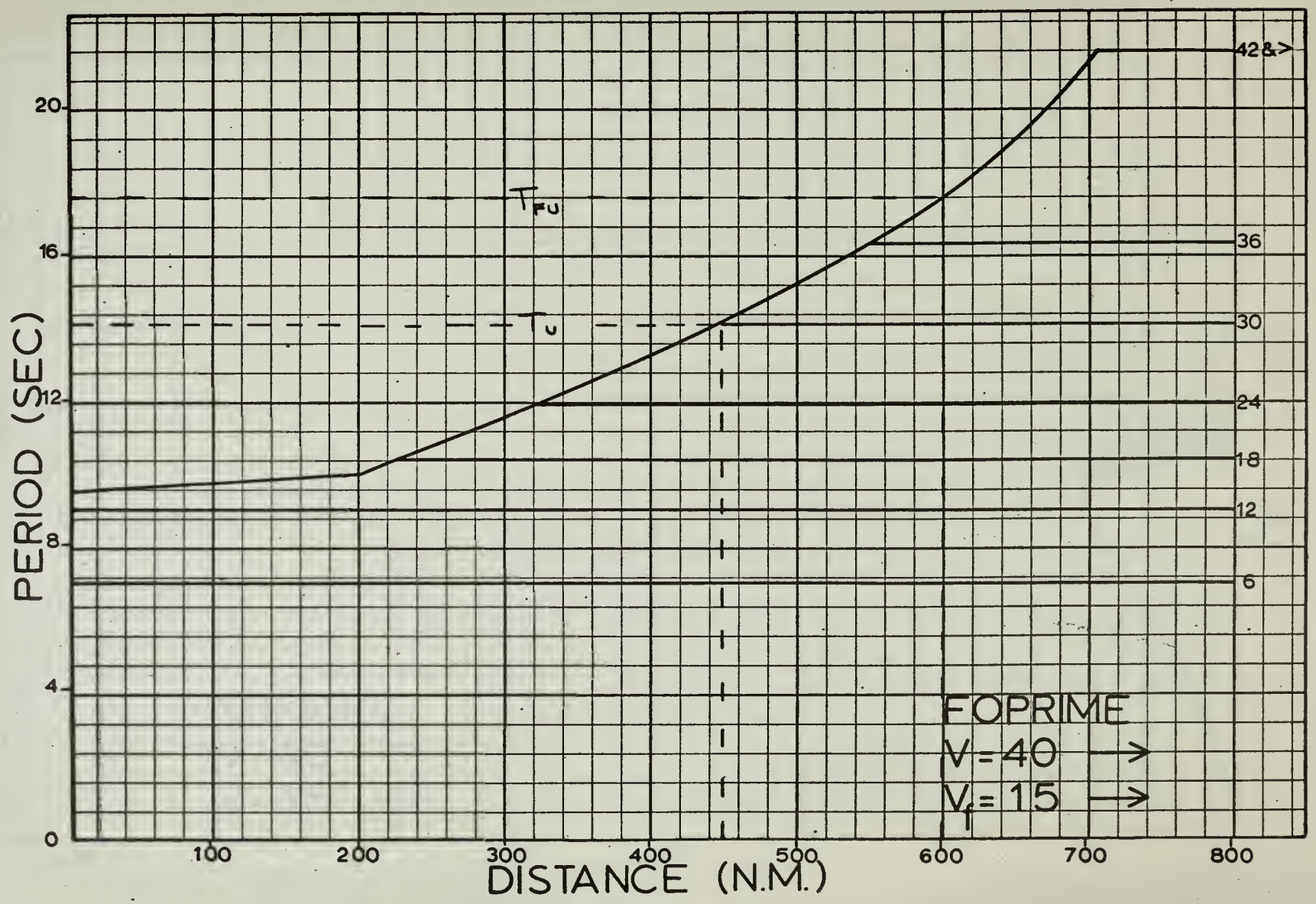

PERIOD (SEC)
0
4
8
12
16
20
T_{FC}
T_c
42&>
36
30
24
18
12
6
FOPRIME
V = 40 →
V_f = 15 →
100
200
300
400
500
600
700
800
DISTANCE (N.M.)

Figure 10.



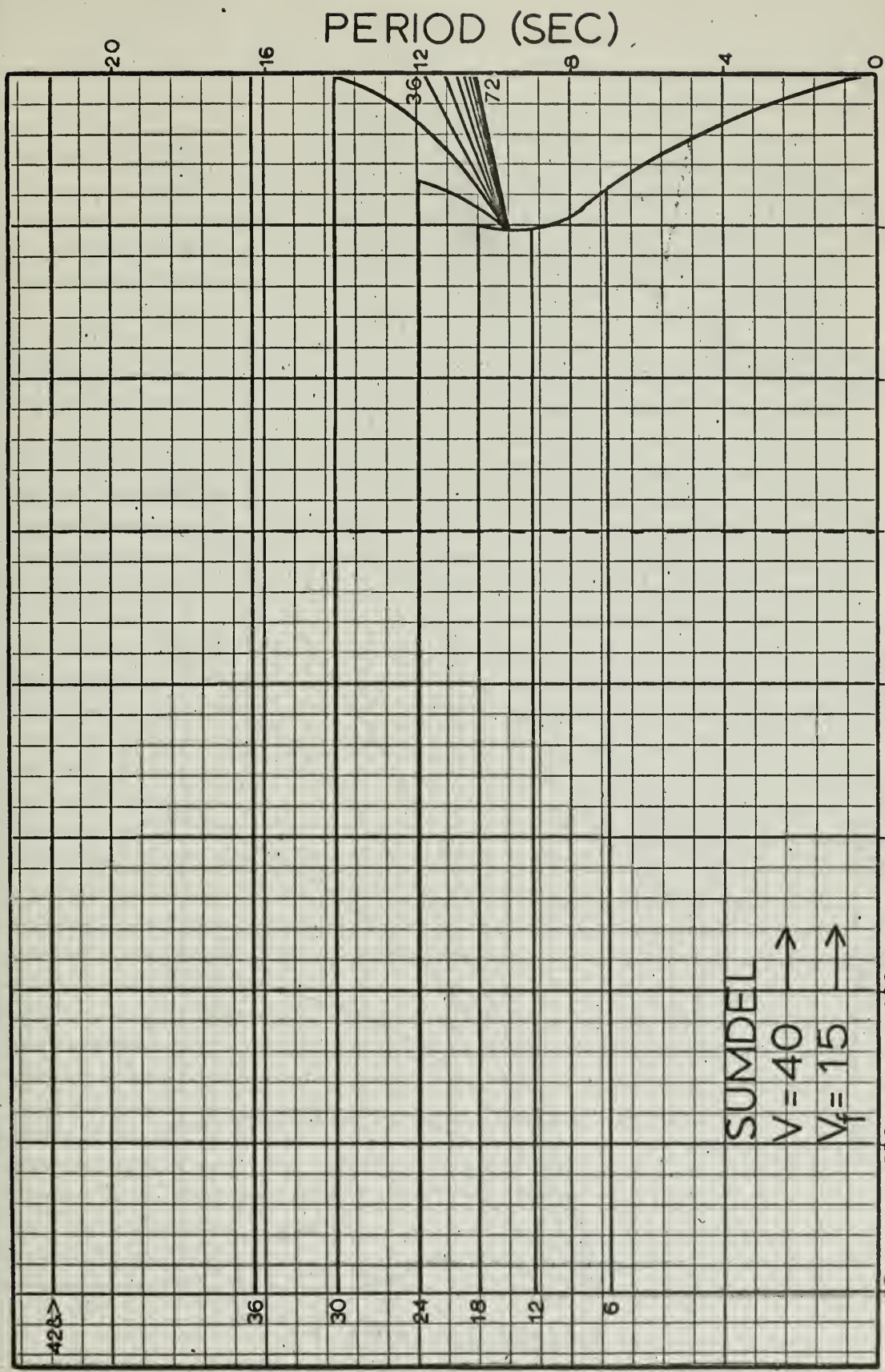

PERIOD (SEC)
20
16
12
8
4
0
36
72
DISTANCE (N.M.)
50
100
150
200
250
300
350
400
SUMDEL
V = 40
Vf = 15
42
36
30
24
18
12
6

Figure 11.



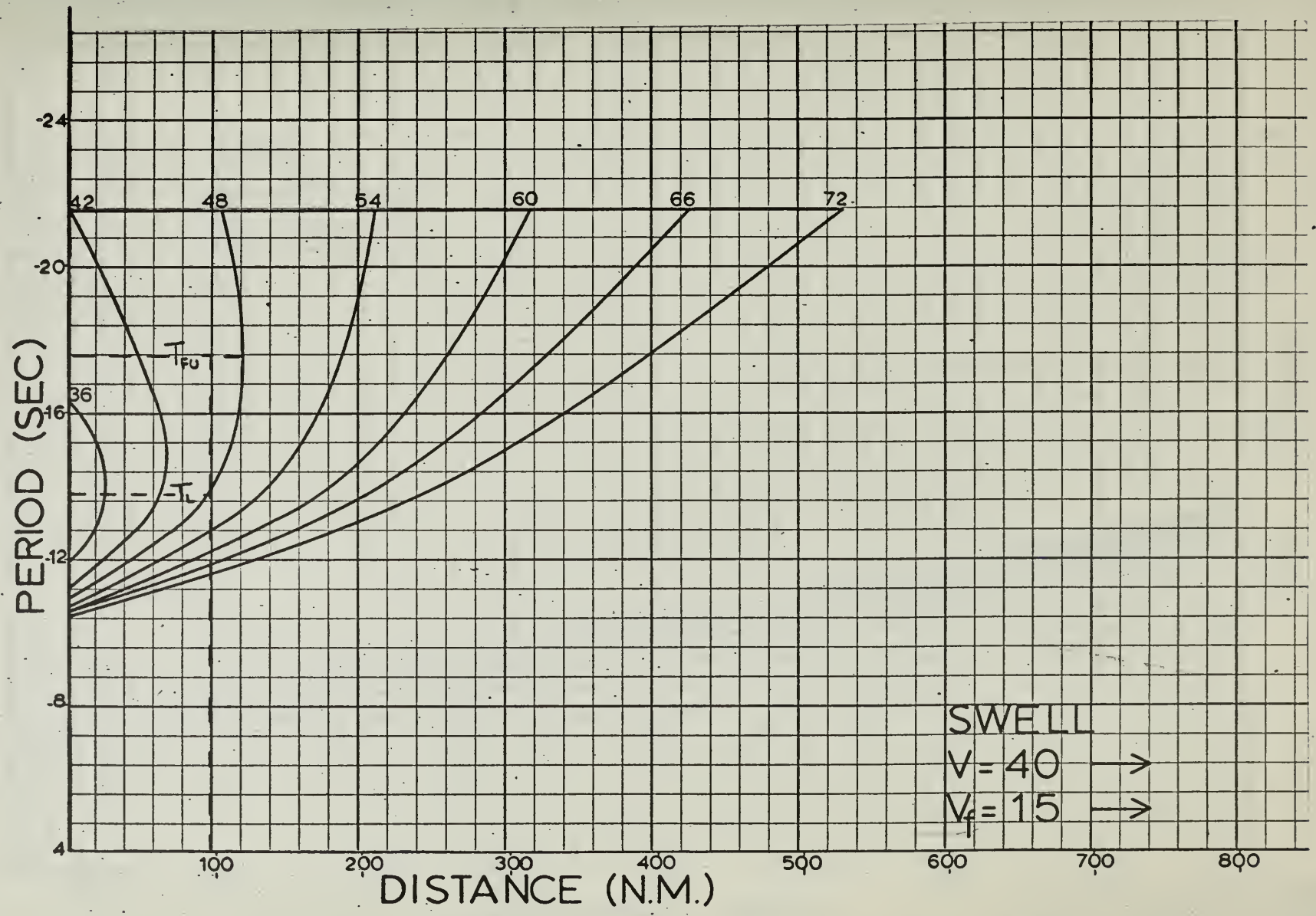

PERIOD (SEC)
24
20
16
12
8
4
42
48
54
60
66
72
36
T_{FU}
T_L
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
SWELL
V = 40 →
V_f = 15 →

Figure 12.



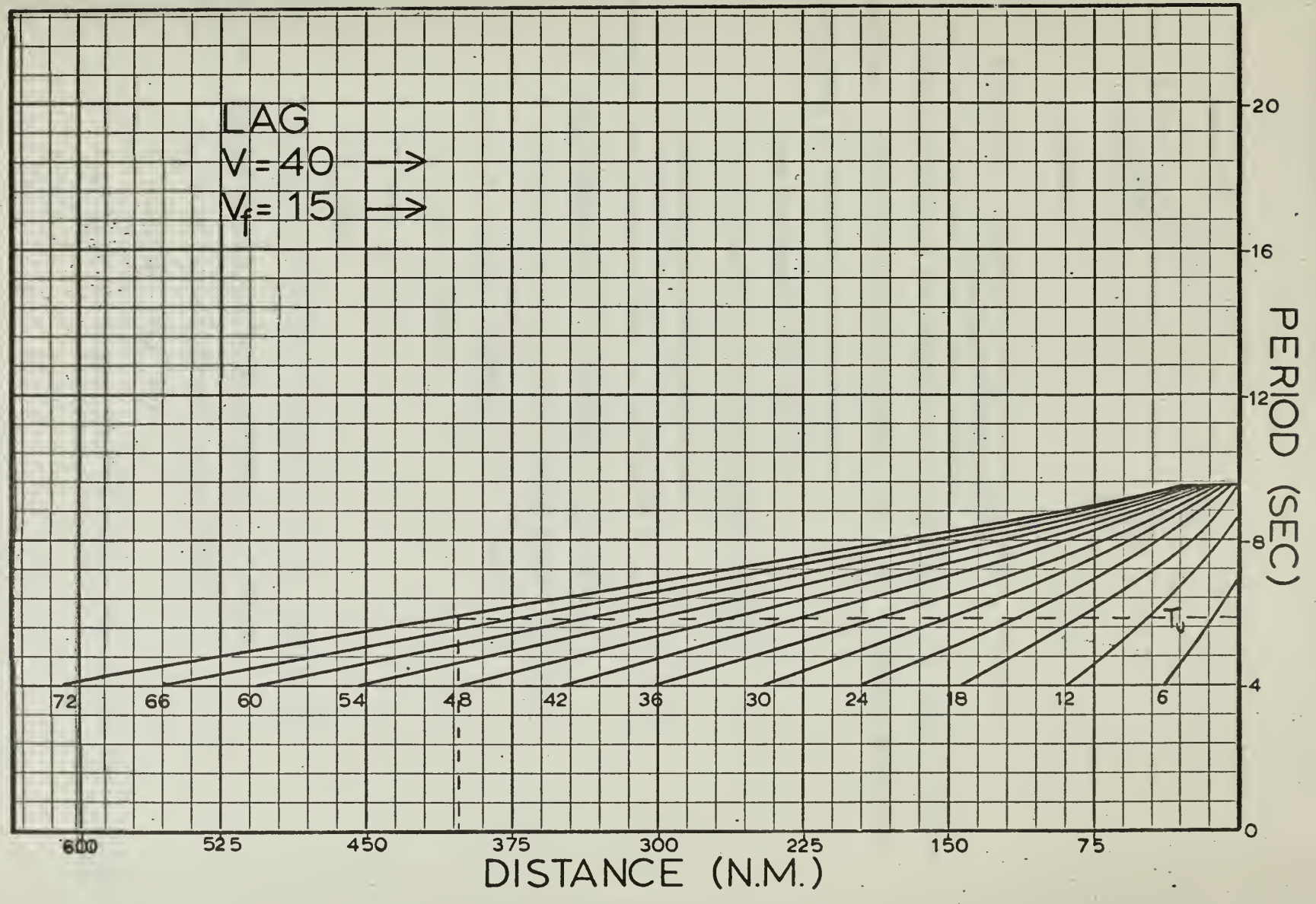

LAG
V = 40 →
Vf = 15 →
72
66
60
54
48
42
36
30
24
18
12
6
T_0
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

Figure 13.



16.3 Example Forecast No. 3: Moving (windward) Fetch Model.

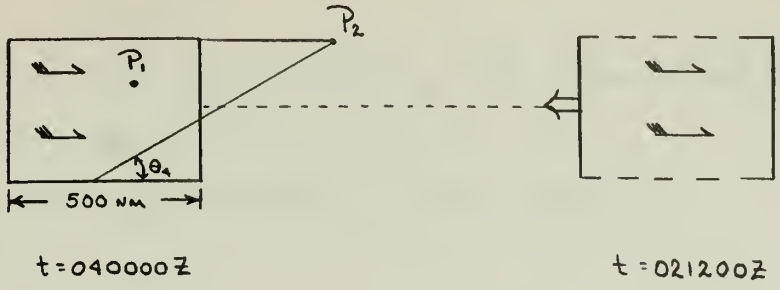


Figure 14. Geographic Positions of P_1 and P_2 Relative to a Moving (windward) Fetch

Fig. 14 portrays the movement of a generating area during the times indicated. From synoptic and prognostic charts the following preliminary information is obtained for the forecast:

1. the positions of P_1 and P_2;
2. V = 30 knots; V_f = 20 knots since 021200Z;
3. a Moving (windward) Fetch Model.

Proceeding with steps outlined in Section 13.4:

a. Sea Forecast for P_1 at 040000Z; t_{ob} = 36 hrs.

1. Distance from P_1 to the leading edge = 400 NM
2. T_u = 9 seconds (SUMDEL graph : Fig. 15)
3. E_u = 21.0 (Table 2)
4. T_L = 0; E_L = 0
5. ΔE_θ = 21.0
6. $H_{1/3} = 2.83\sqrt{21.0} = 2.83(4.6) = 13$ ft. (Table 3)

b. Swell Forecast for P_2 at 040000Z; t_{ob} = 36 hrs.

1. T_{FU} = 10 seconds (SUMDEL graph: Fig. 15)
2. R_o = 450 NM (Fig. 14)
3. $T_U = T_{FU}$ = 10 seconds (SUMDEL graph: Fig. 15 and SWELL graph: Fig. 16)

   T_L = 0

4. $E_U = 29.0$; (Table 2)

   $E_L = 0$

5. $\theta_3 = 0$, $\theta_4 = +40^\circ$, $S_\theta = .38$ (Fig. 14 and Table 1)

6. $\Delta E_\theta = (29)\ (.38) = 11.0$

7. $H_{1/3} = 2.83\sqrt{11.0} = 9.3$ ft. (Table 3)

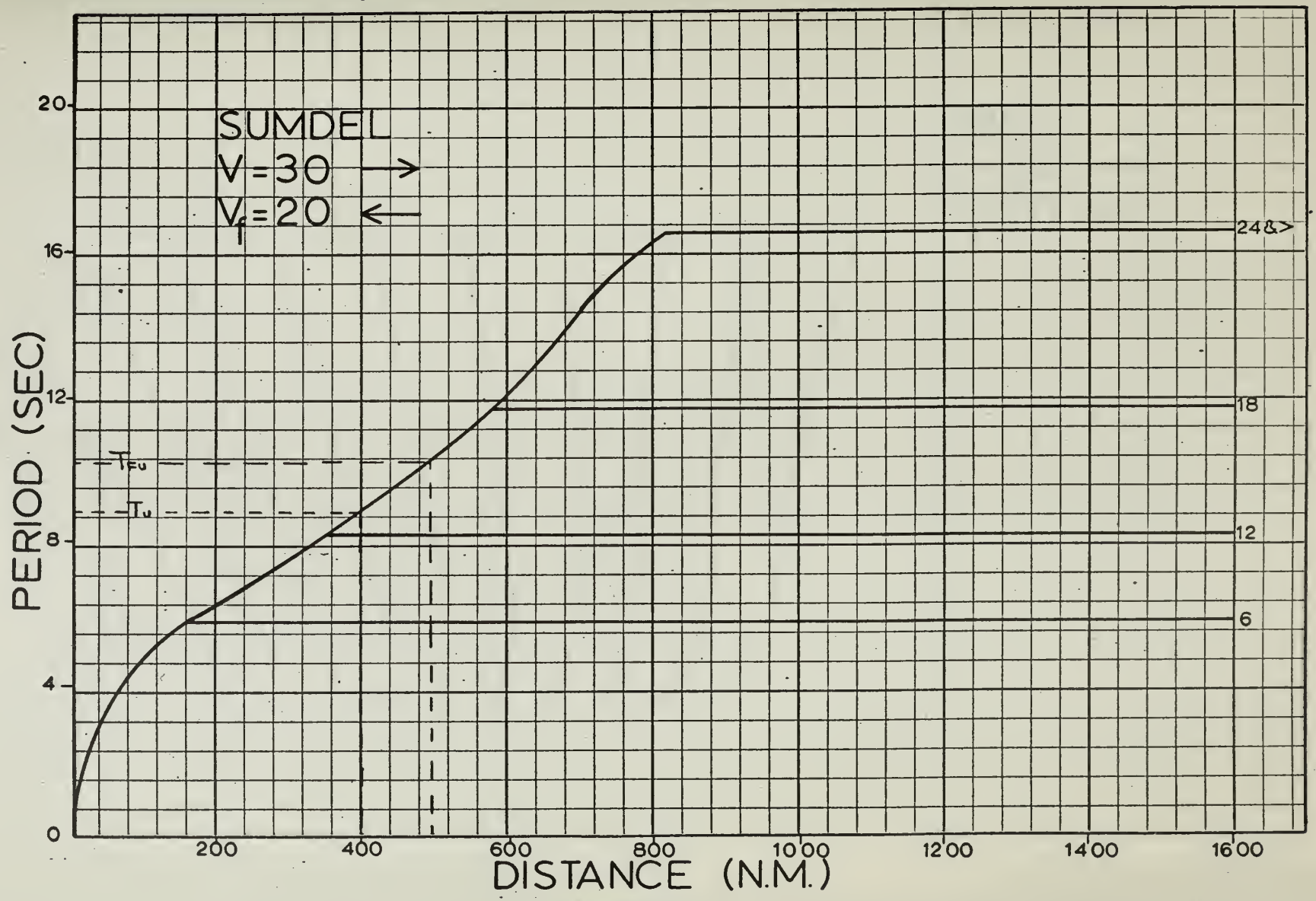

SUMDEL
V=30 →
V_f=20 ←
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
24&>
18
12
6
T_Eu
T_u

Figure 15.



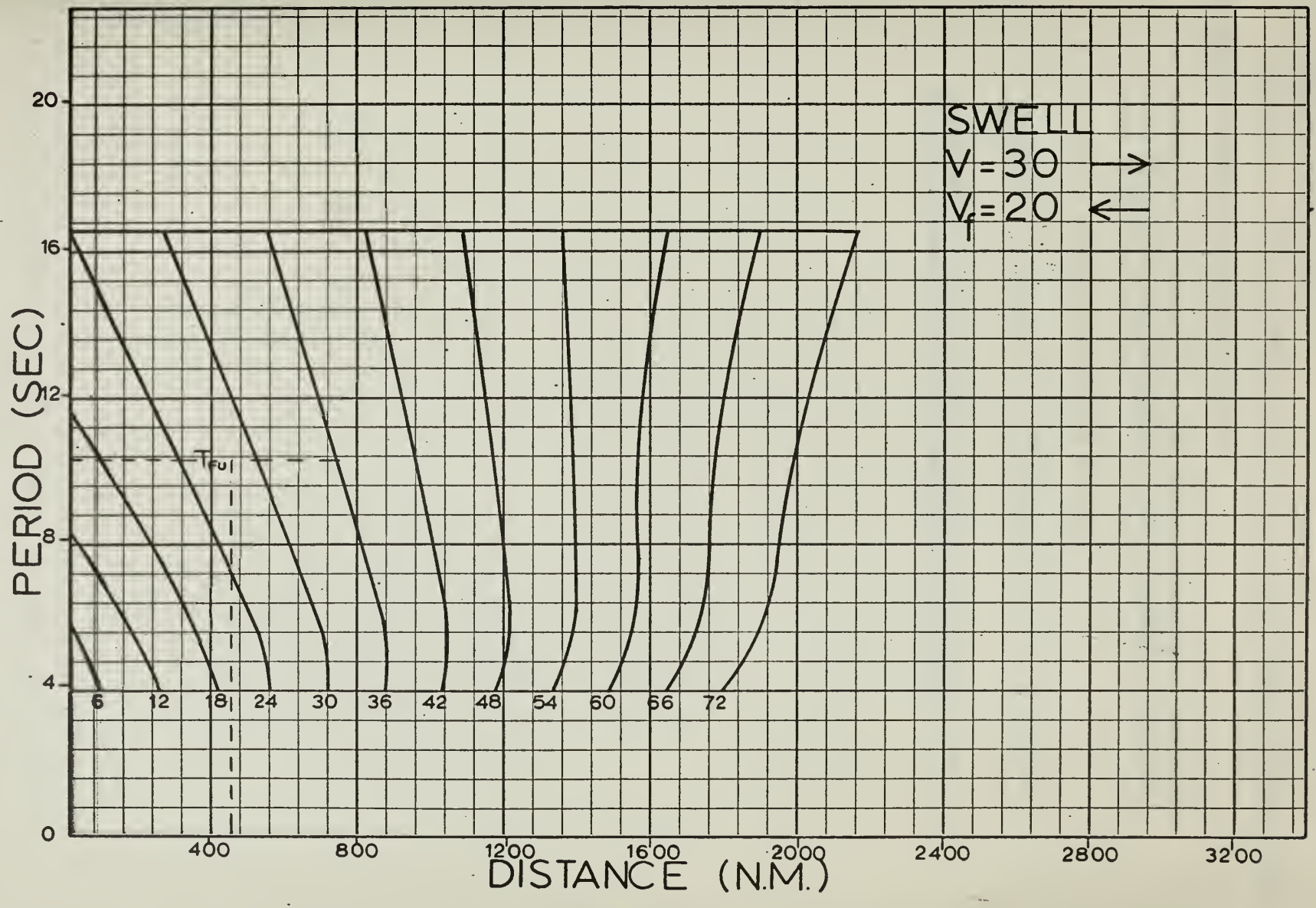

SWELL
V = 30
Vf = 20
PERIOD (SEC)
20
16
12
8
4
0
TFU
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

Figure 16.

17. Further Investigations

Following is a list of subjects which the authors hope to study further as time and computer facilities permit:

1. completion of models where the wind is blowing at some angle with respect to the direction of fetch movement other than zero or 180^{o};

2. extending the duration beyond 72 hours;

3. completion of a model for a dying sea and one with variable winds;

4. programming in SCRAP computer language for adaptation to U. S. Navy Fleet Numerical Weather Facility forecasting.

18. Graphs

Included in this section are the graphs of LAG, FOPRIME, SUMDEL and SWELL, divided into sub-sections:

18.1 Stationary Fetch Model; pages 44-62

18.2 Moving (leeward) Fetch Model; pages 63-212

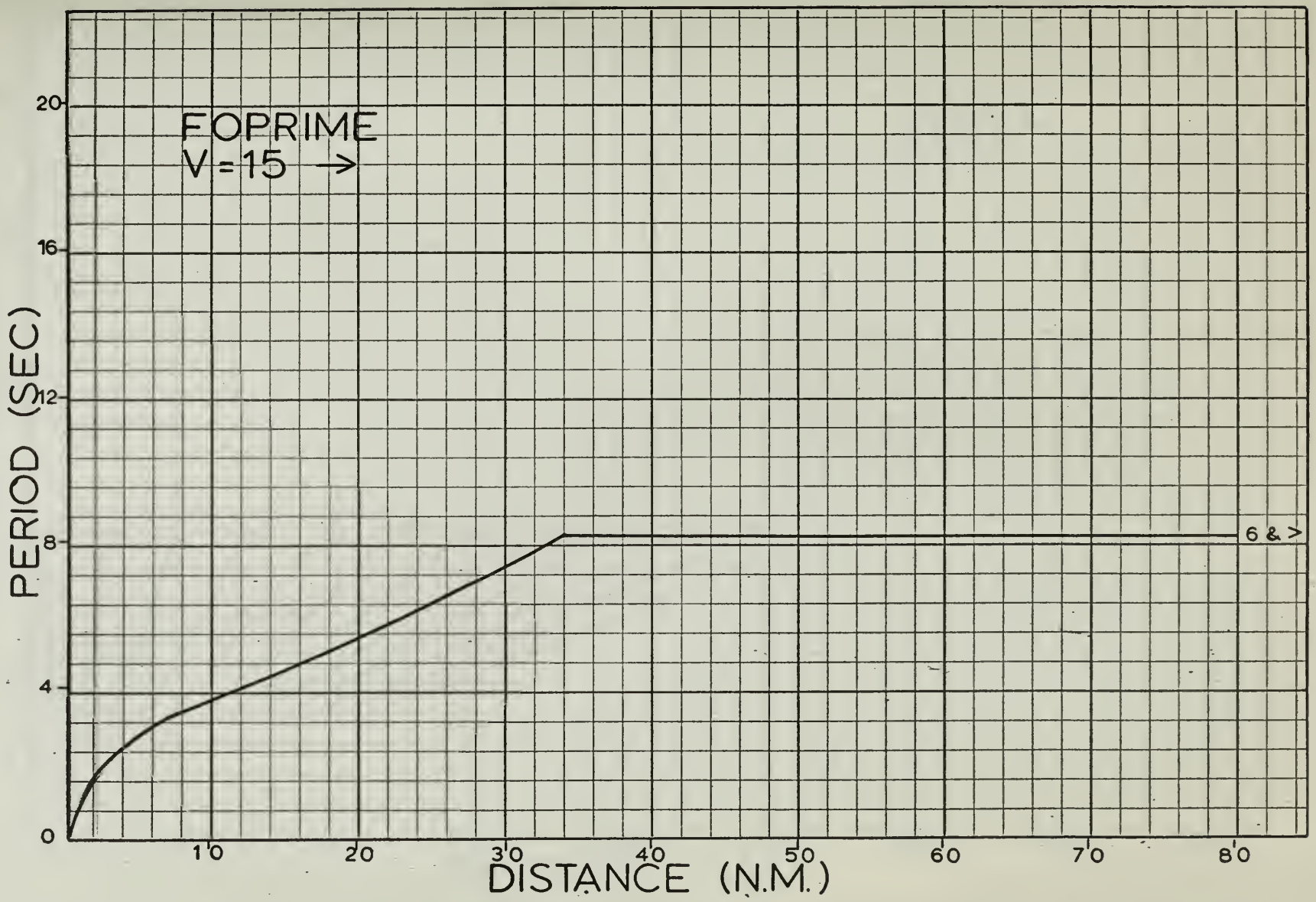
18.3 Moving (windward) Fetch Model; pages 213-303

The graphs within the sub-sections are arranged by increasing wind speeds and associated increasing fetch speeds.

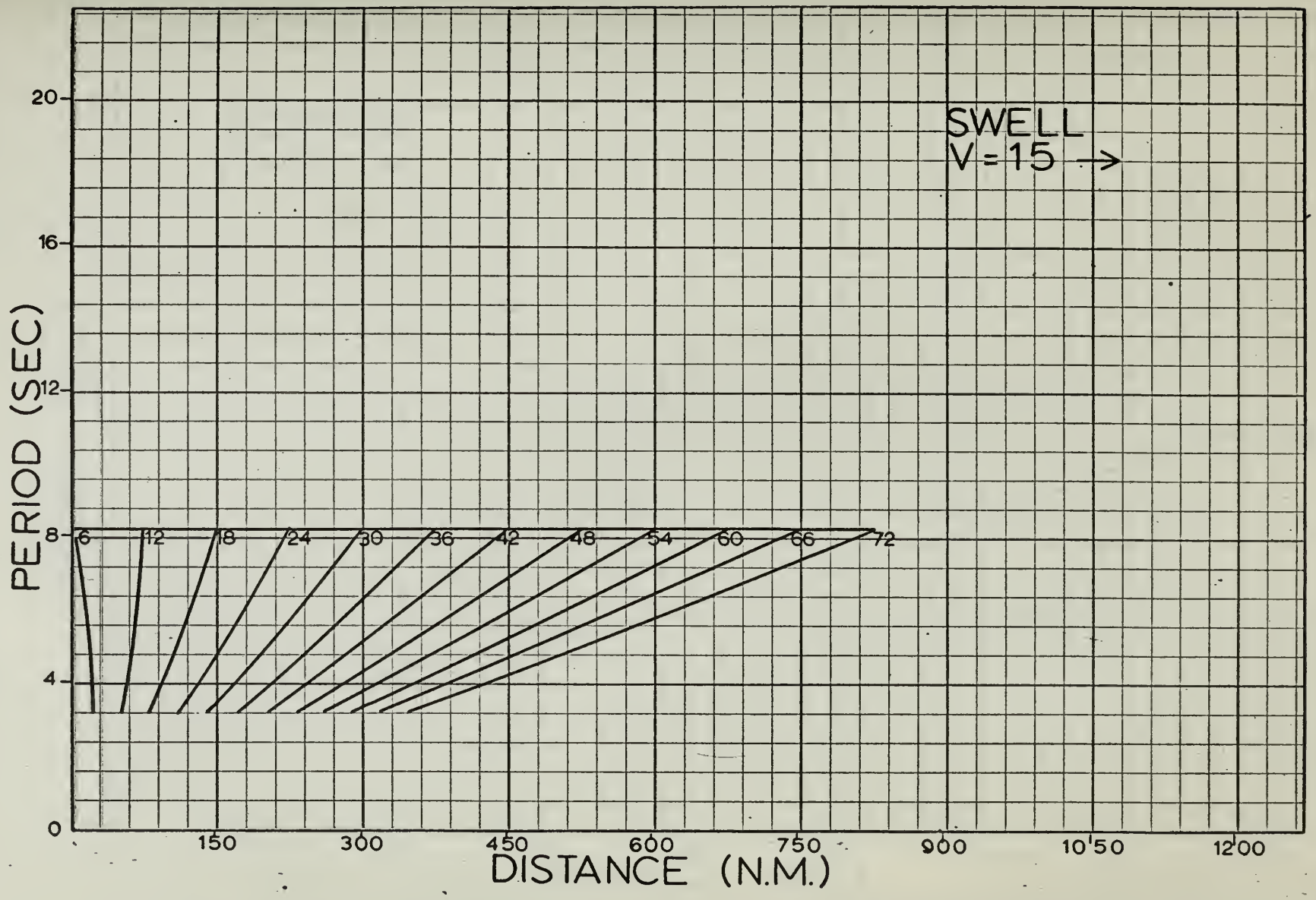
18.1 Stationary Fetch Model Graphs

INDEX OF GRAPHS

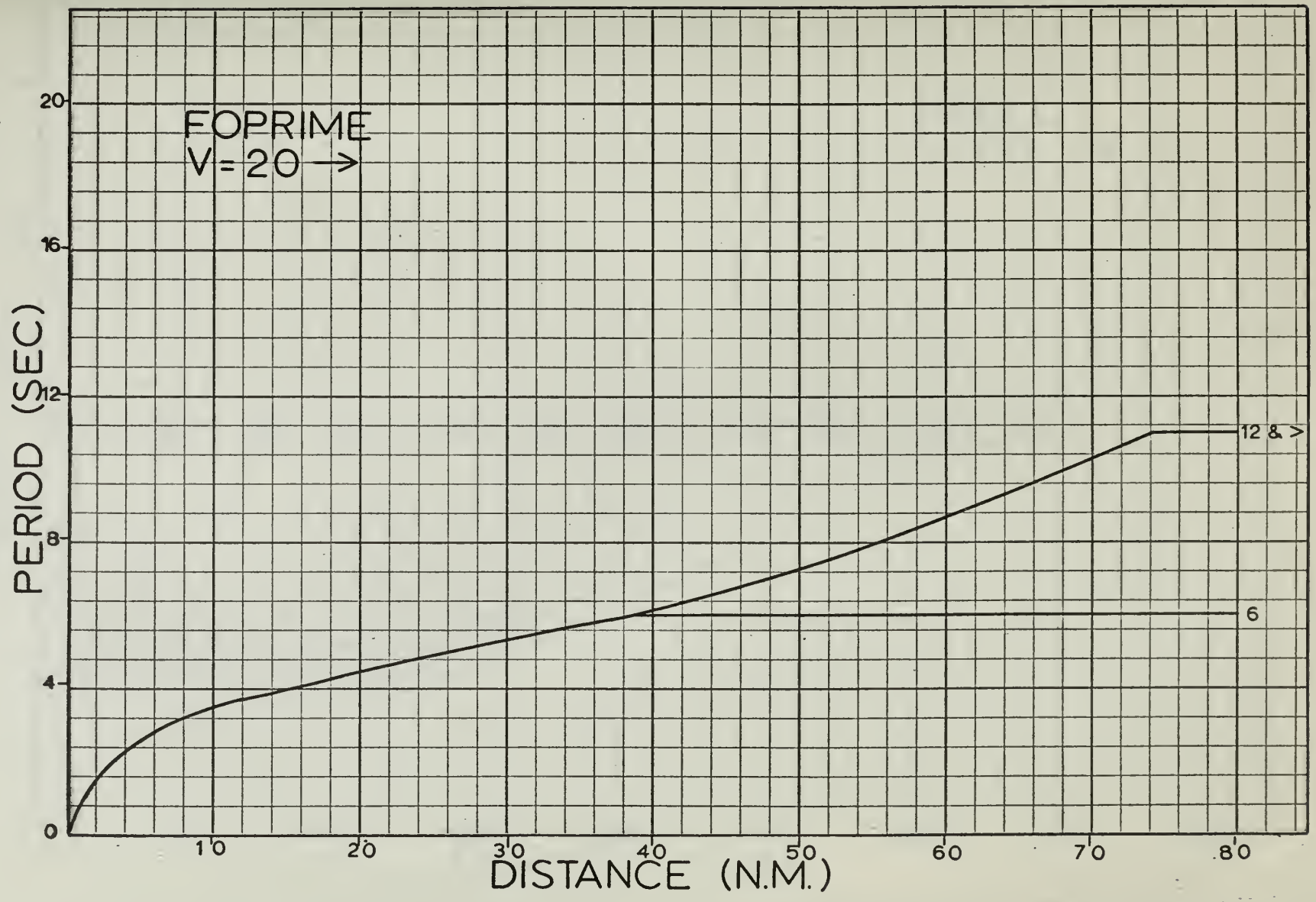
Wind Speed (V)	Inclusive Pages
15	45-46
20	47-48
25	49-50
30	51-52
35	53-54
40	55-56
45	57-58
50	59-60
55	61-62

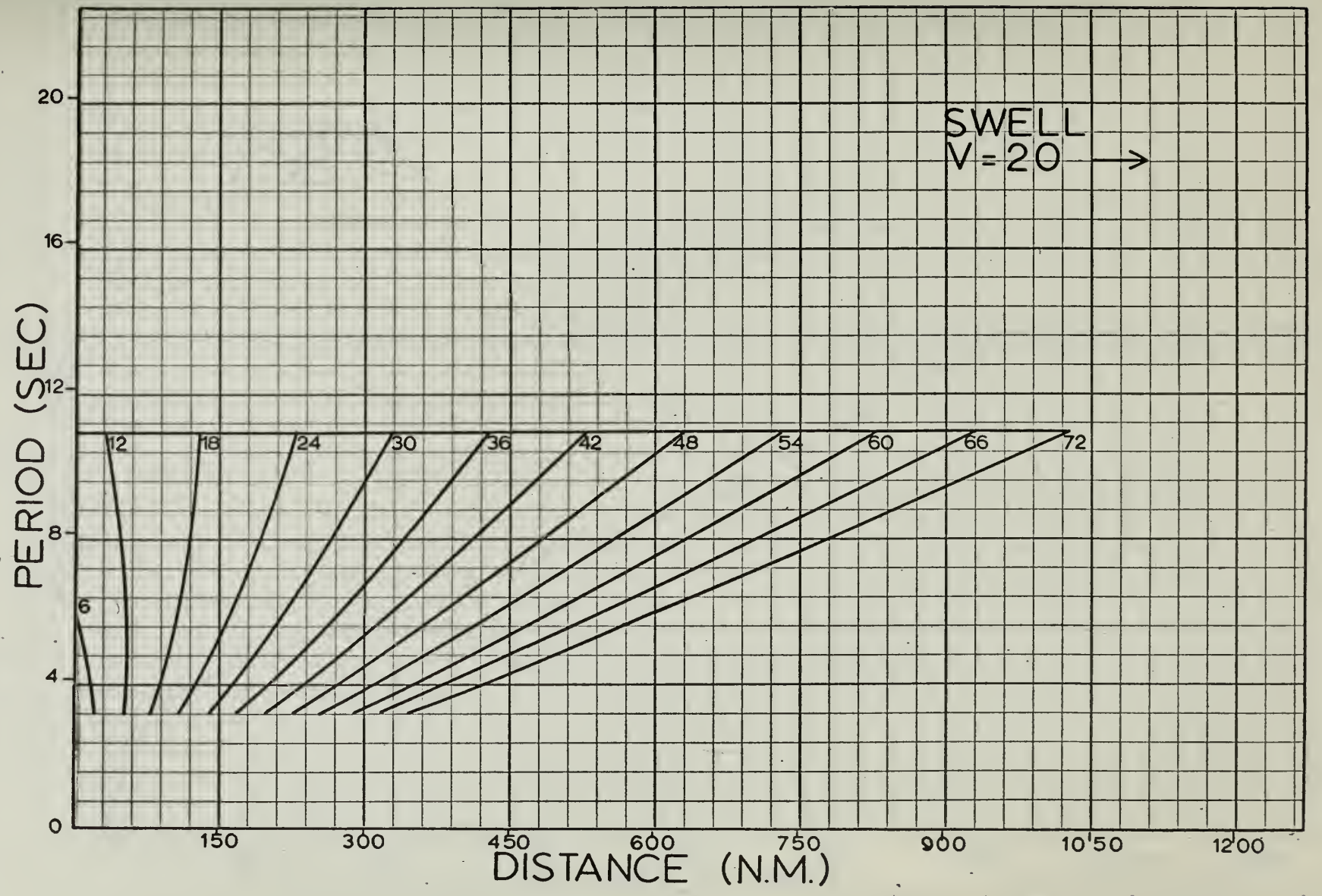

FOPRIME
V=15 →
PERIOD (SEC)
0
4
8
12
16
20
6 & >
1'0
2'0
3'0
4'0
5'0
6'0
7'0
8'0
DISTANCE (N.M.)



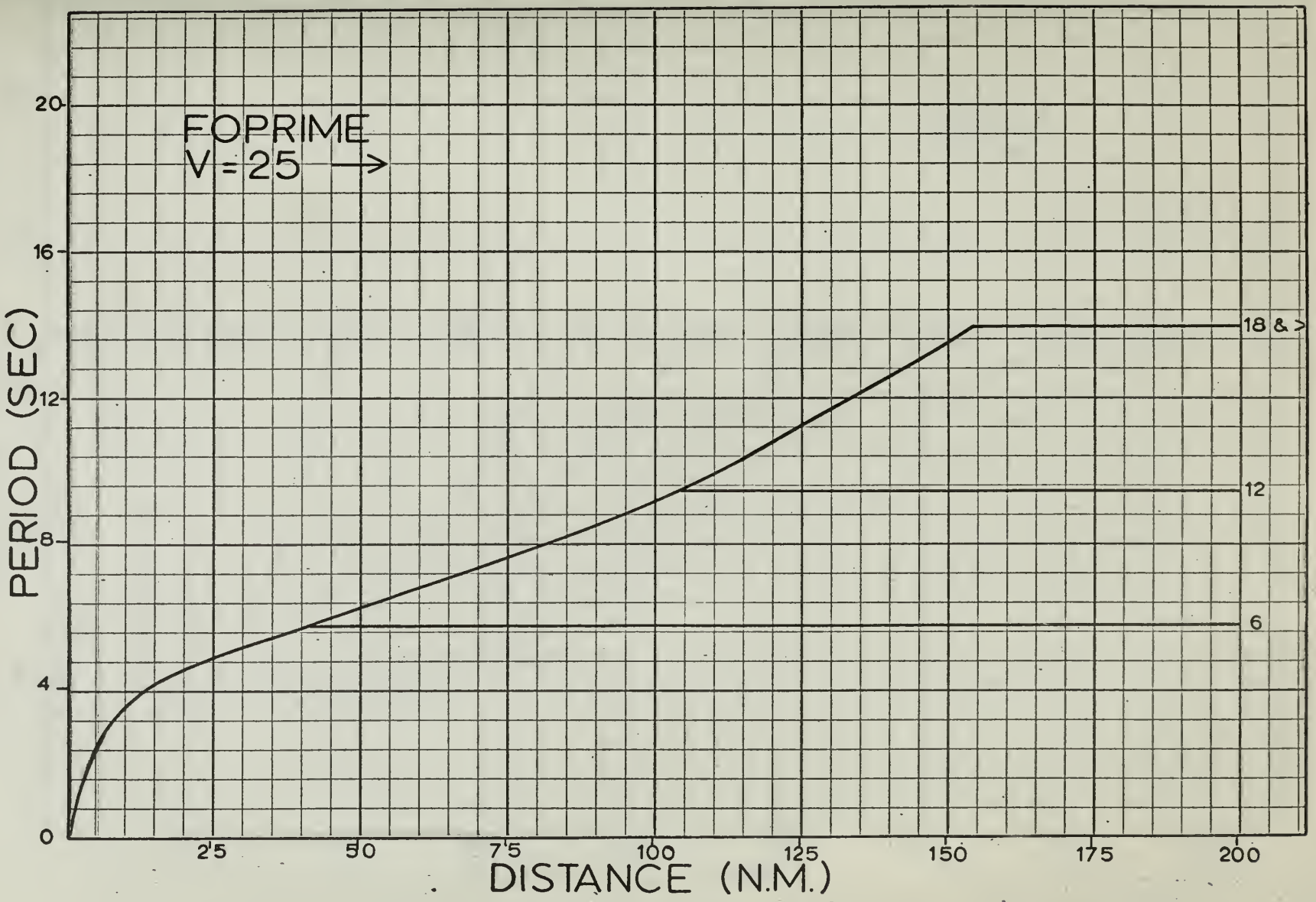

SWELL
V=15 →
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

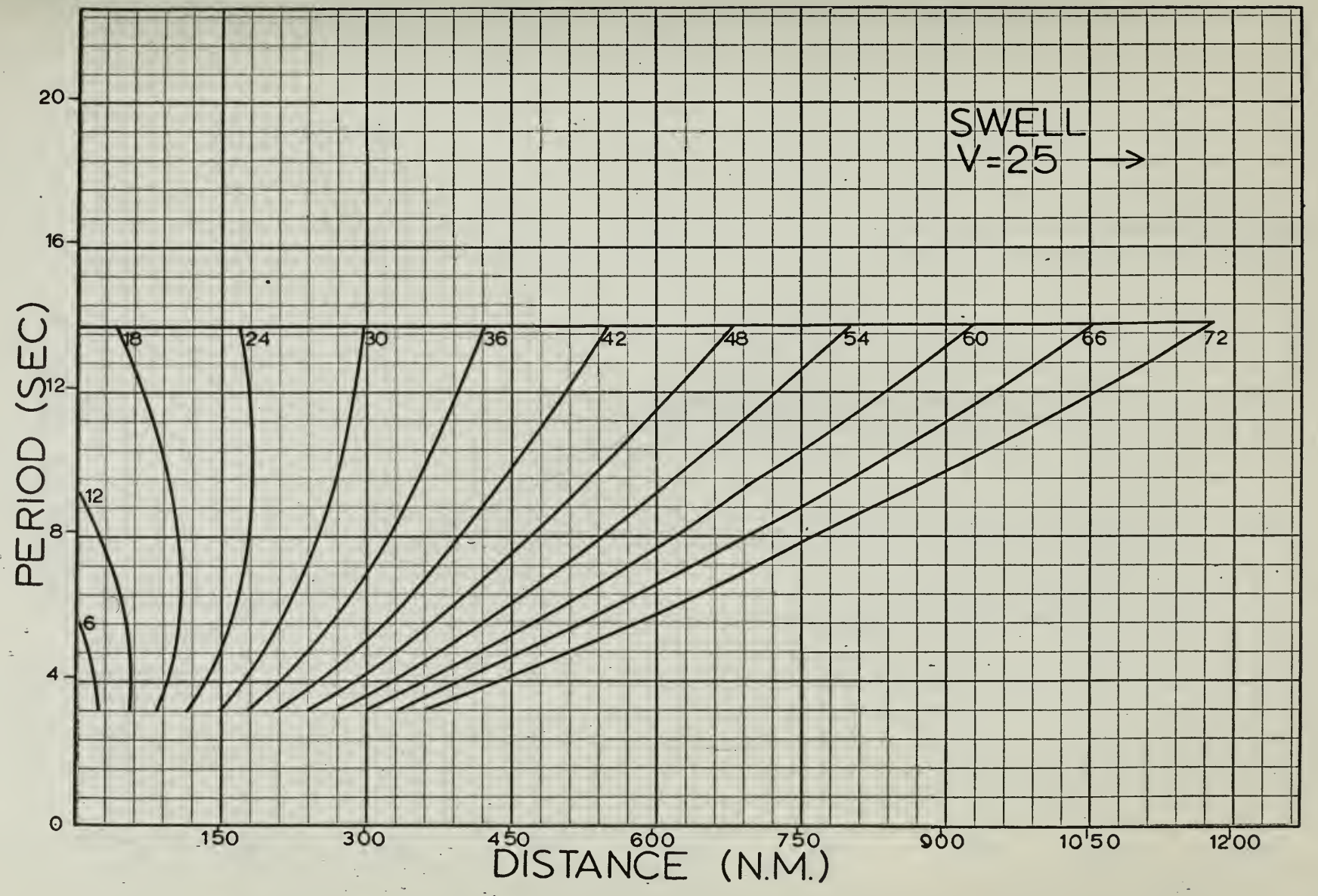


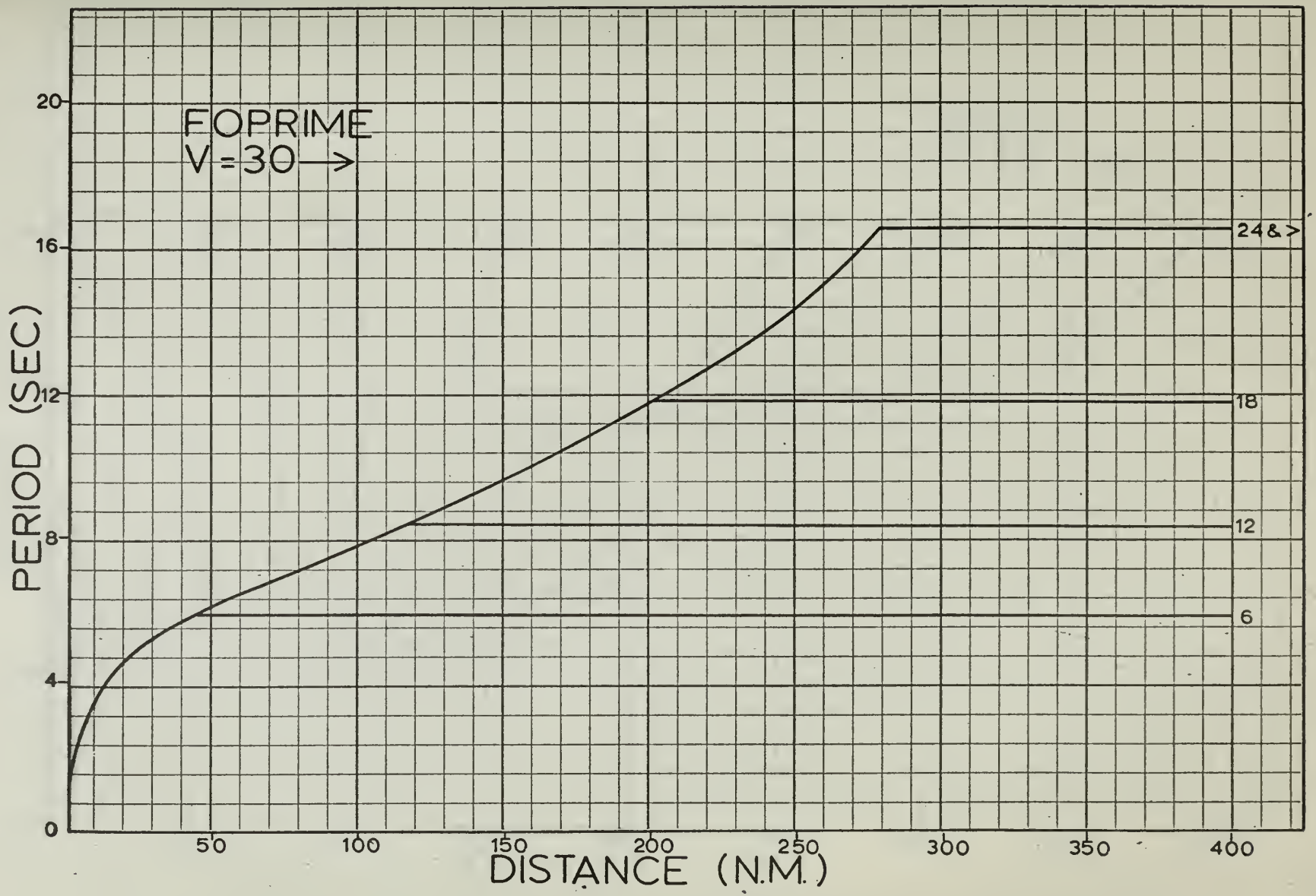

FOPRIME
V=20 →
PERIOD (SEC)
0
4
8
12
16
20
1'0
2'0
3'0
4'0
5'0
6'0
7'0
8'0
DISTANCE (N.M.)
12 & >
6

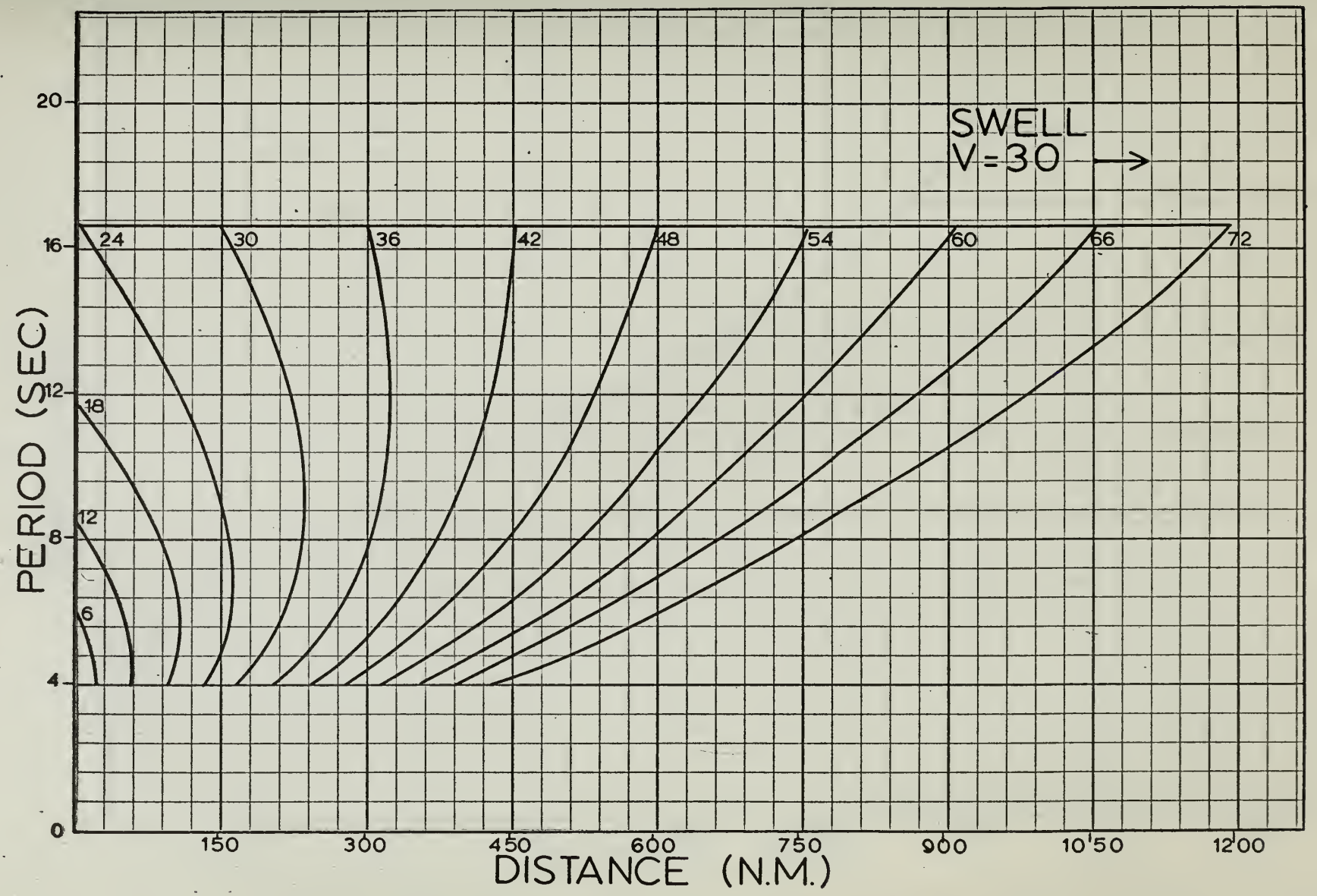

SWELL
V = 20
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
150
300
450
600
750
900
1050
1200
6
12
18
24
30
36
42
48
54
60
66
72



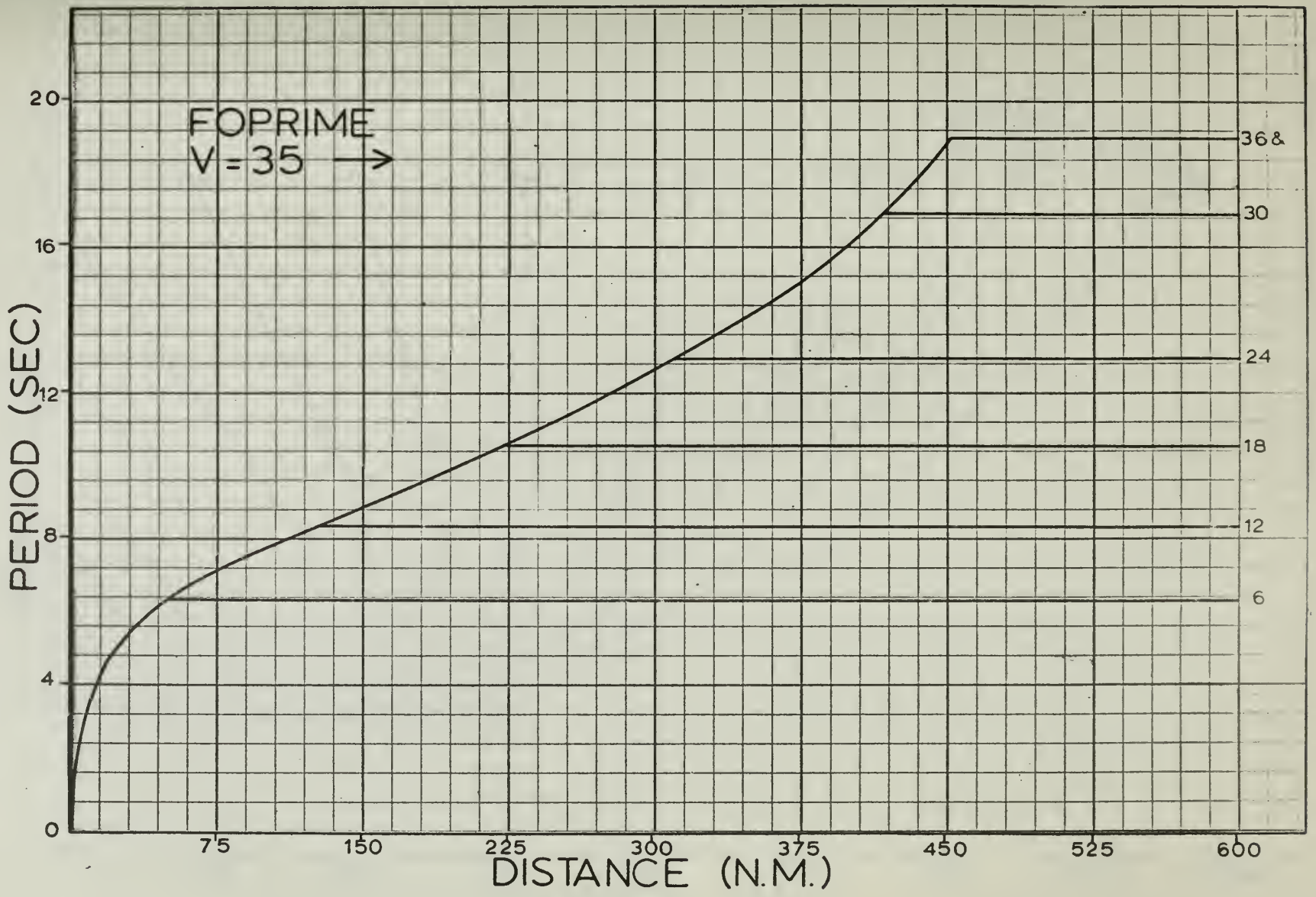

FOPRIME
V=25 →
PERIOD (SEC)
0
4
8
12
16
20
25
50
75
100
125
150
175
200
DISTANCE (N.M.)
18 & >
12
6

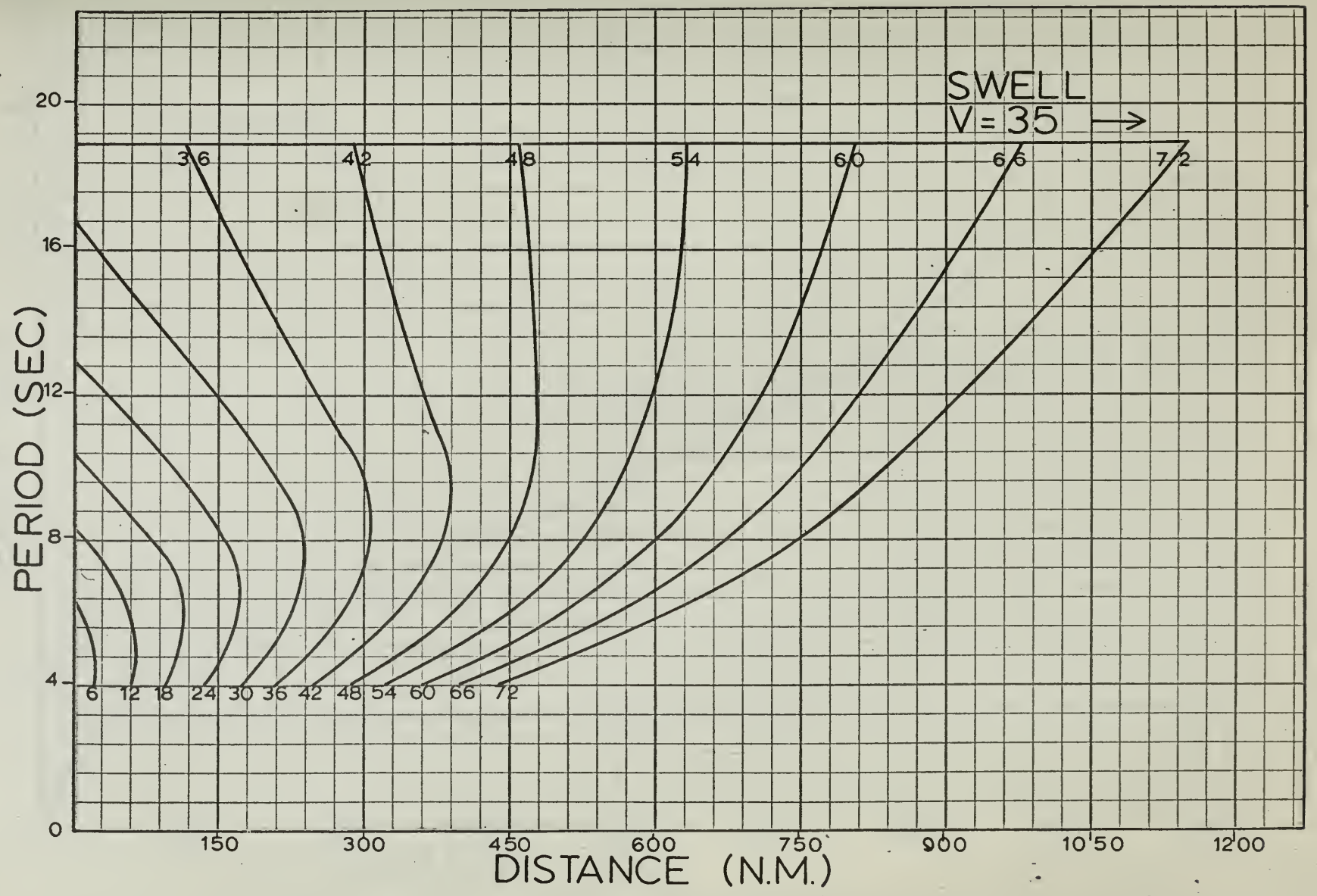

SWELL
V=25 →
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
150
300
450
600
750
900
1050
1200
6
12
18
24
30
36
42
48
54
60
66
72


FOPRIME
V=30 →
PERIOD (SEC)
0
4
8
12
16
20
24&>
18
12
6
50
100
150
200
250
300
350
400
DISTANCE (N.M.)

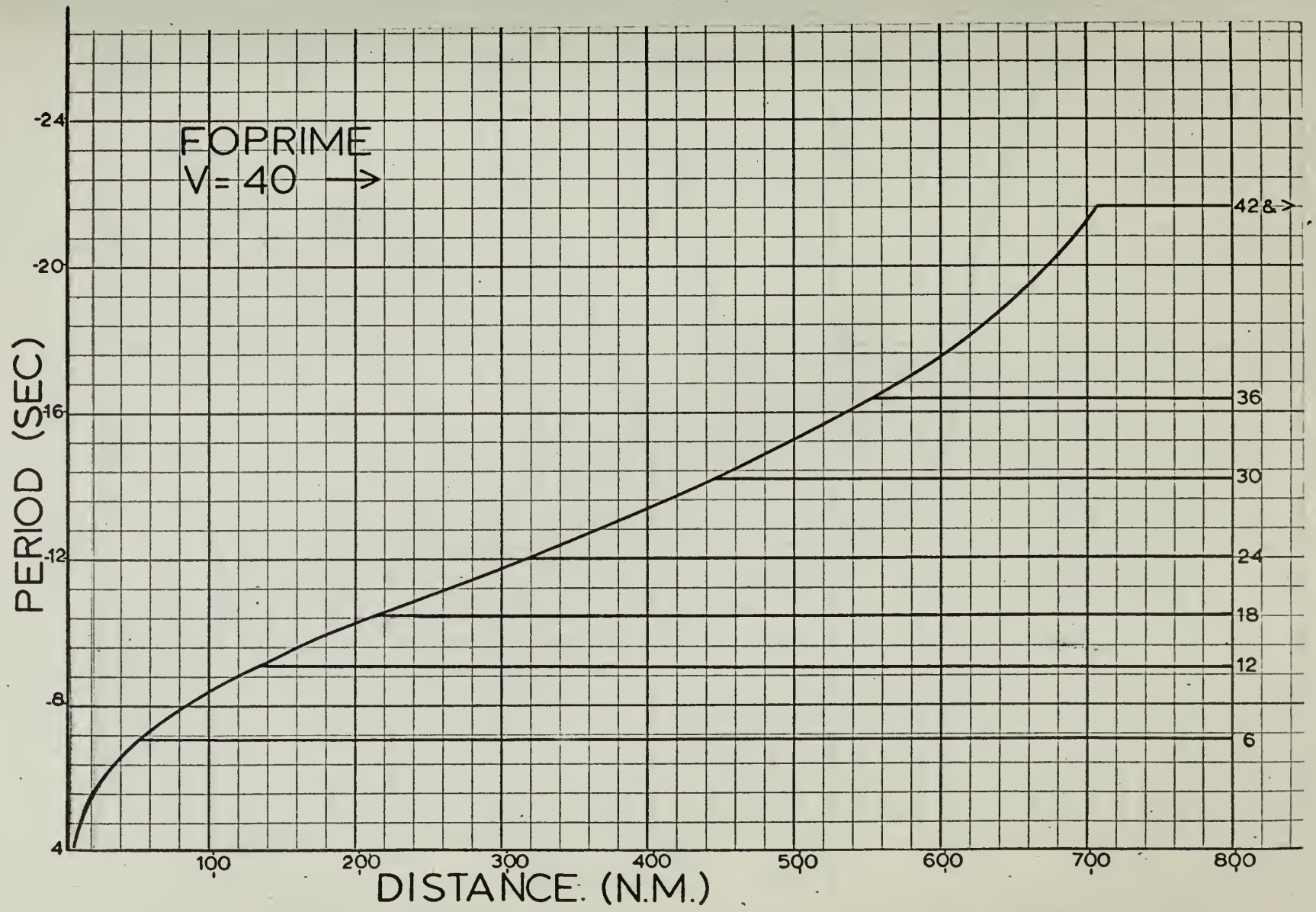

SWELL
V=30 →
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
150
300
450
600
750
900
1050
1200
6
12
18
24
30
36
42
48
54
60
66
72



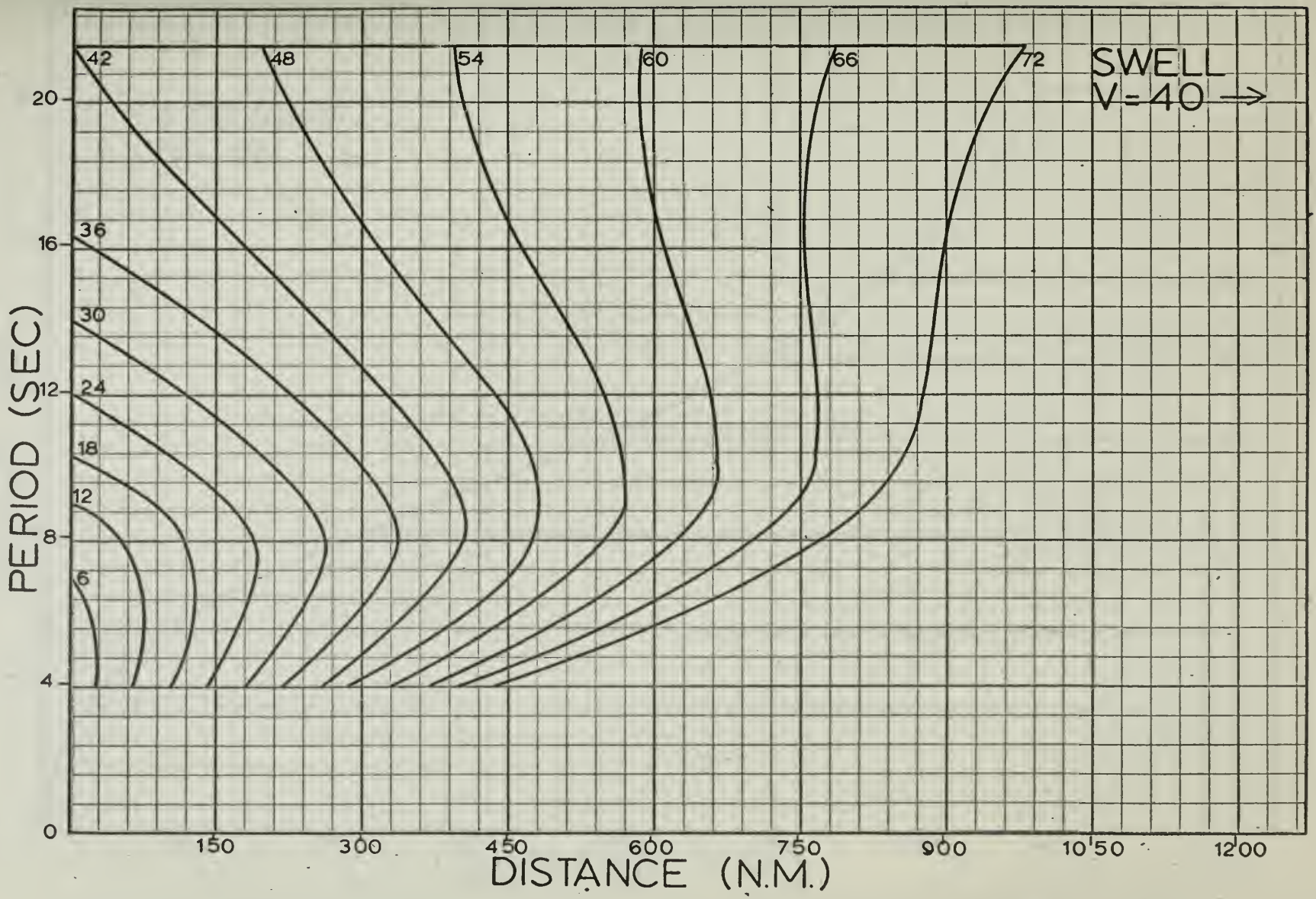

FOPRIME
V=35 →
PERIOD (SEC)
0
4
8
12
16
20
36&
30
24
18
12
6
75
150
225
300
375
450
525
600
DISTANCE (N.M.)

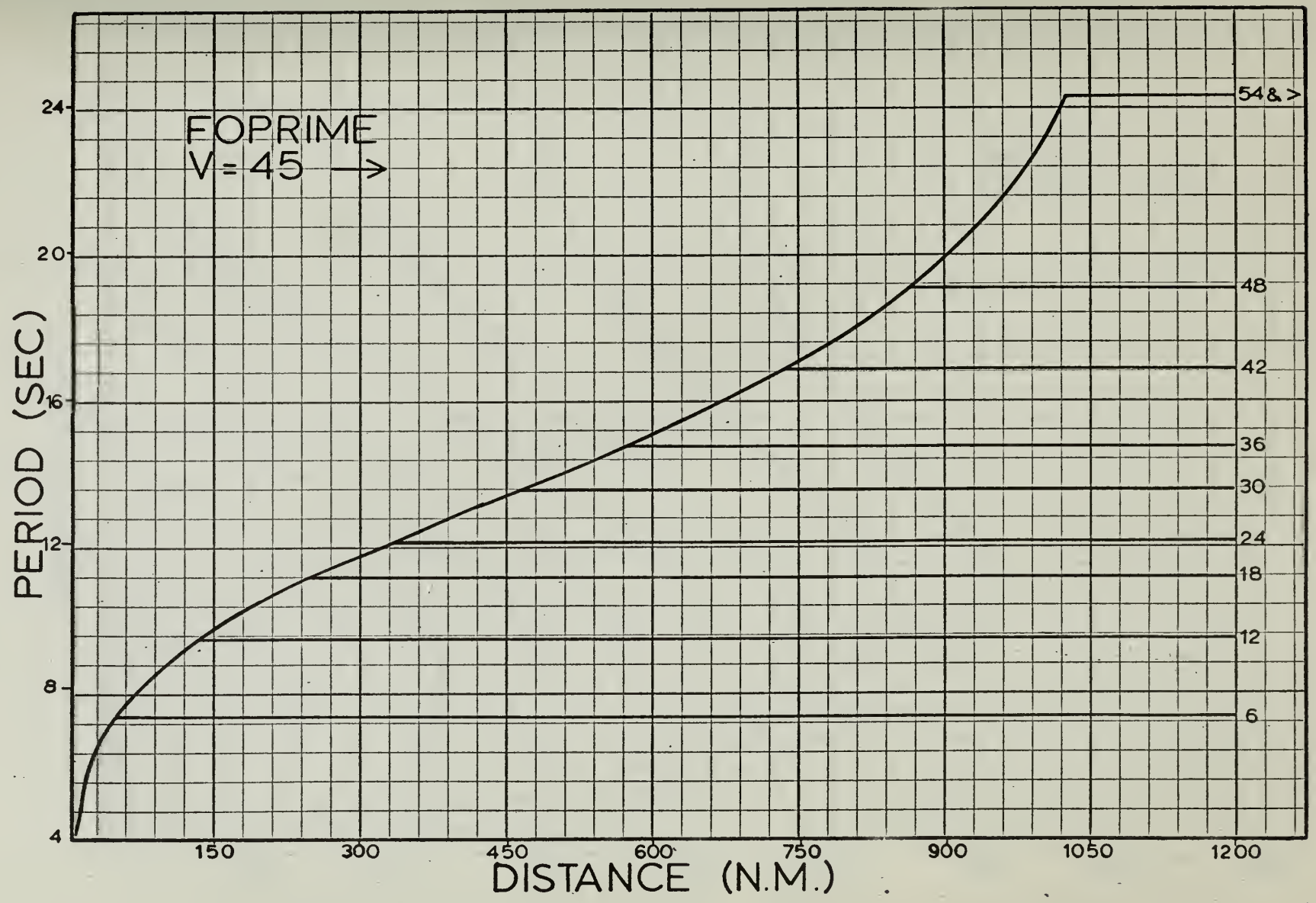

SWELL
V = 35 →
36
42
48
54
60
66
72
6
12
18
24
30
36
42
48
54
60
66
72
PERIOD (SEC)
0
4
8
12
16
20
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)



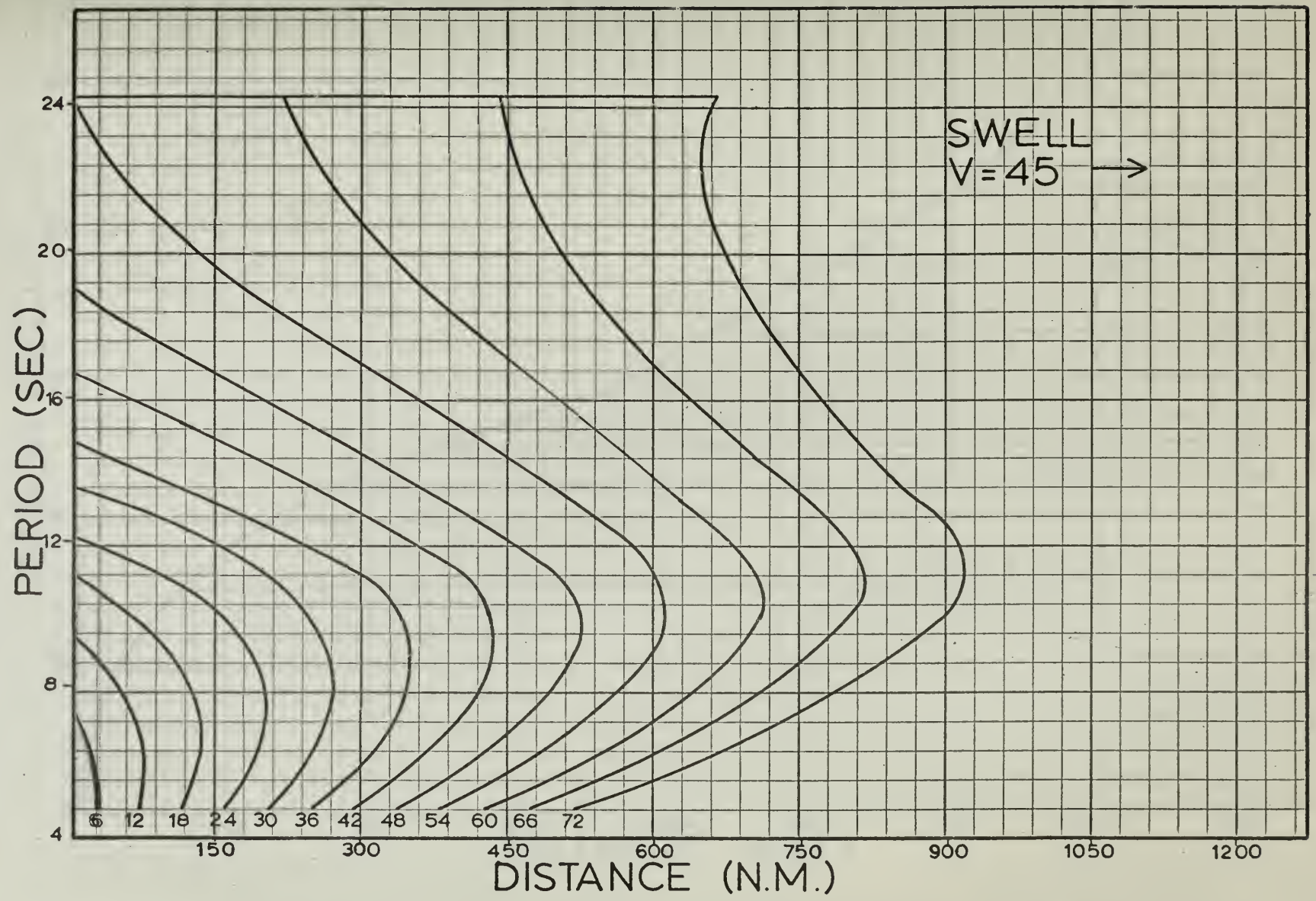

FOPRIME
V = 40 →
PERIOD (SEC)
24
20
16
12
8
4
42 &>
36
30
24
18
12
6
100
200
300
400
500
600
700
800
DISTANCE (N.M.)



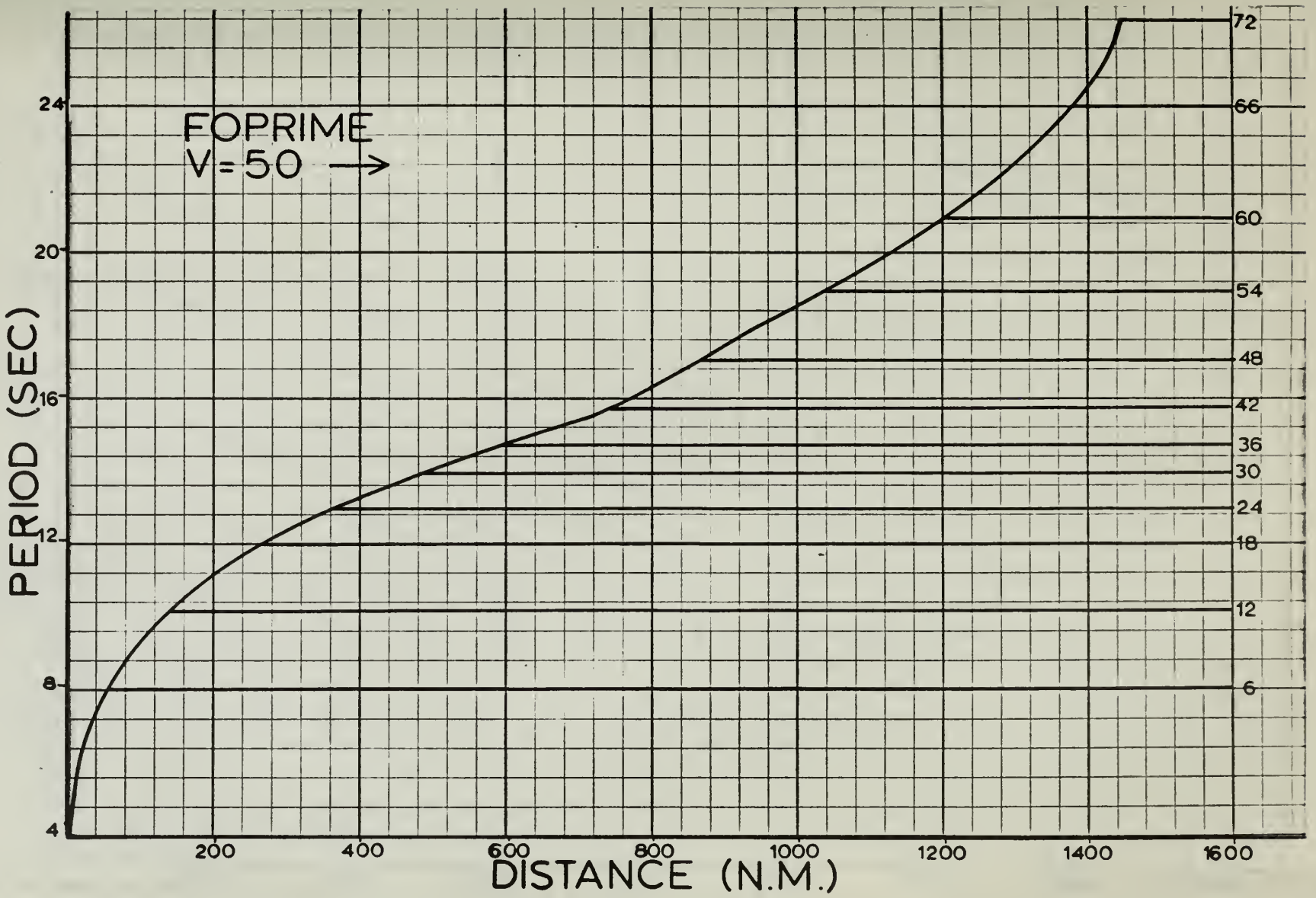

SWELL
V=40 →
42
48
54
60
66
72
36
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)


FOPRIME
V = 45 →
PERIOD (SEC)
24
20
16
12
8
4
54 &>
48
42
36
30
24
18
12
6
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

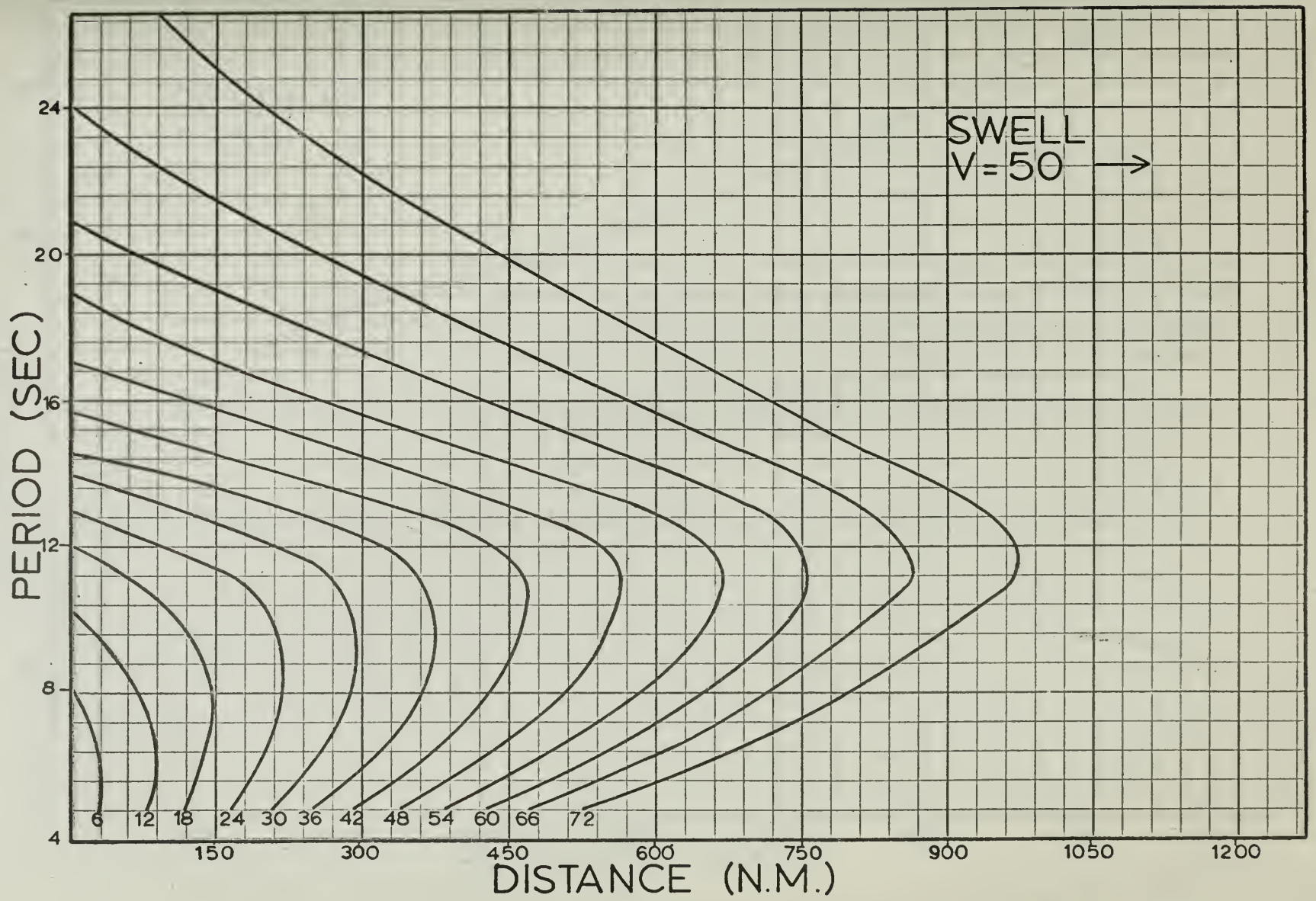


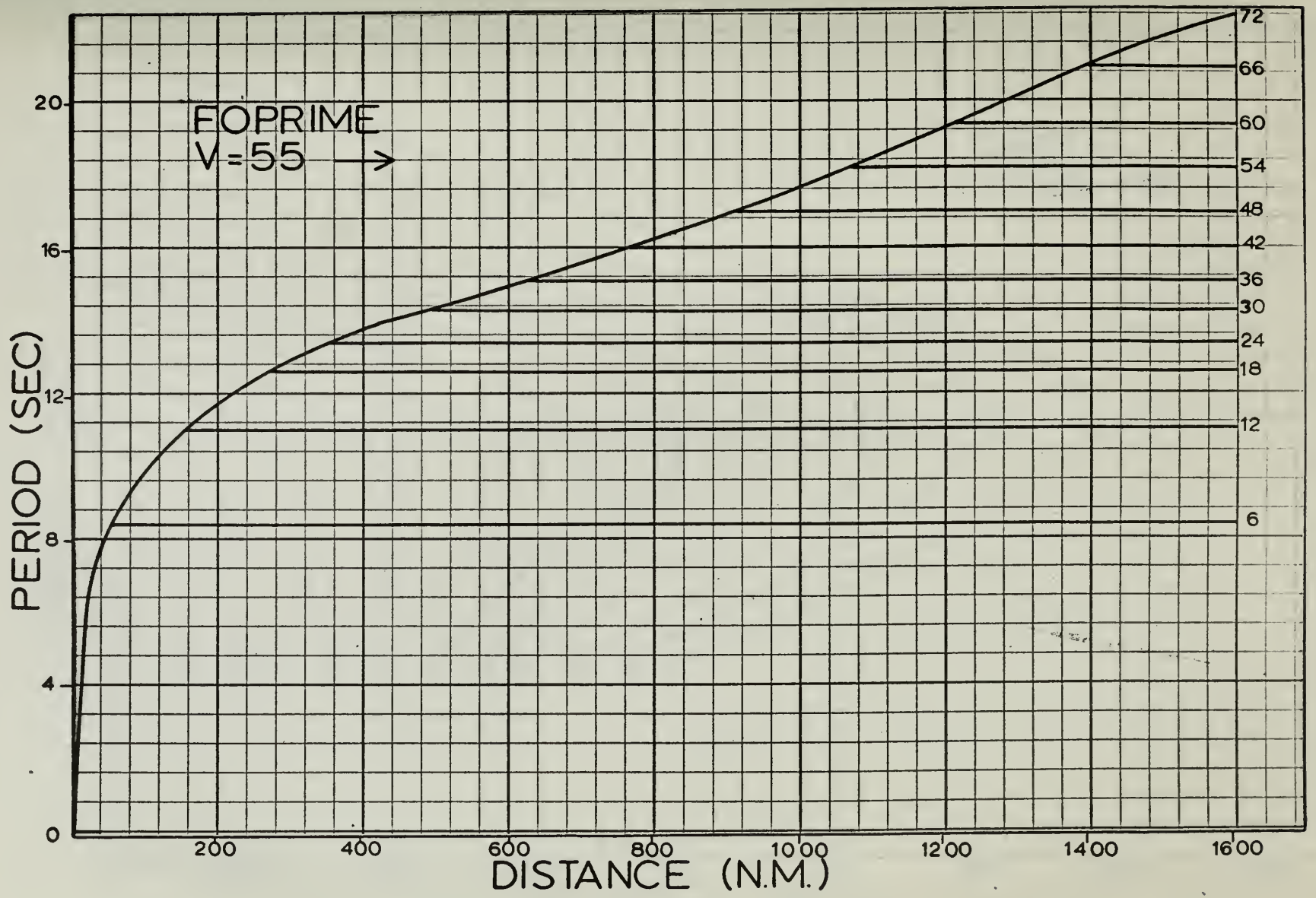

SWELL
V=45 →
PERIOD (SEC)
24
20
16
12
8
4
6 12 18 24 30 36 42 48 54 60 66 72
150 300 450 600 750 900 1050 1200
DISTANCE (N.M.)



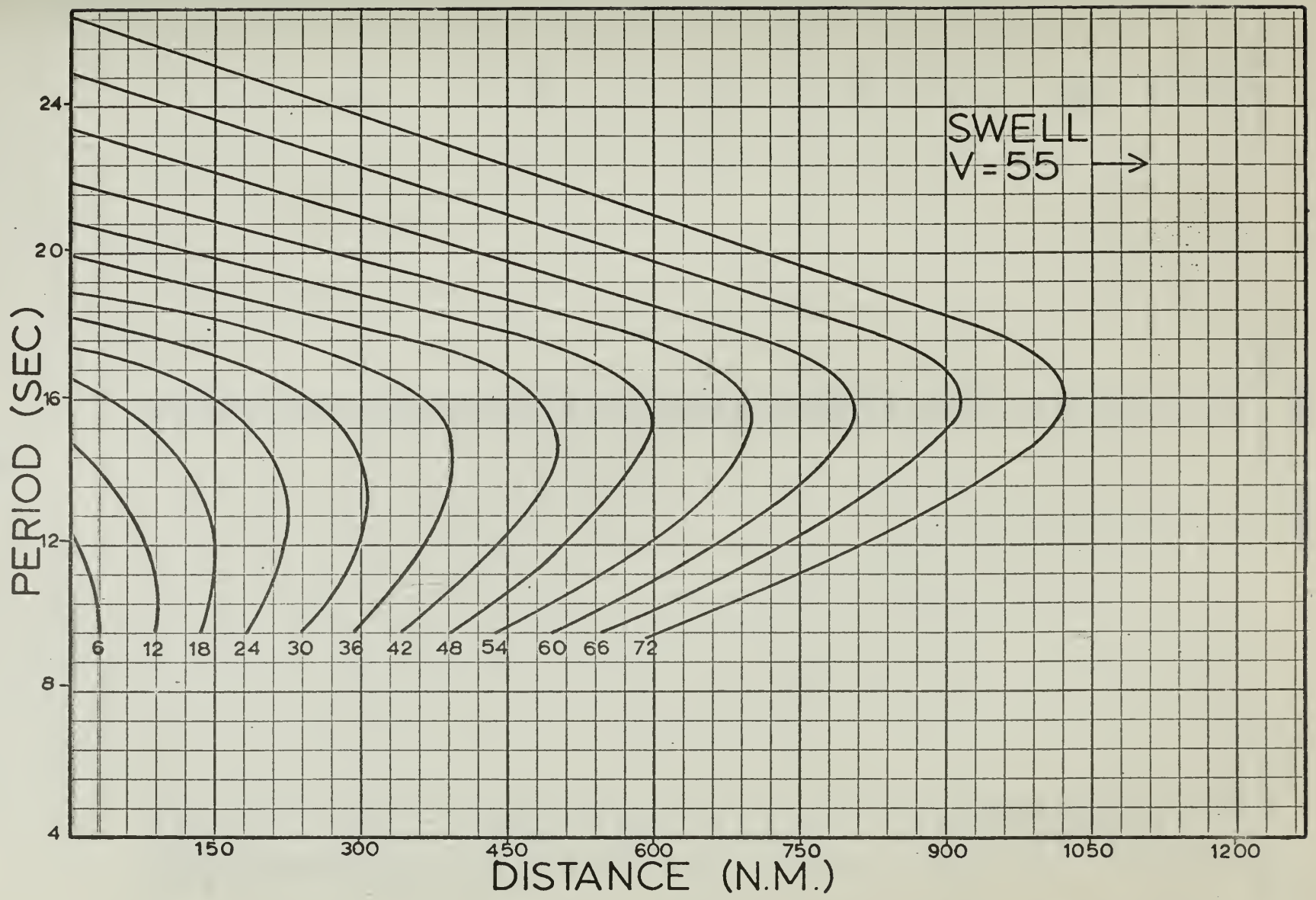

FOPRIME
V=50 →
PERIOD (SEC)
4
8
12
16
20
24
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
72
66
60
54
48
42
36
30
24
18
12
6




SWELL
V=50 →
PERIOD (SEC)
24
20
16
12
8
4
6
12
18
24
30
36
42
48
54
60
66
72
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)


FOPRIME
V=55
72
66
60
54
48
42
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

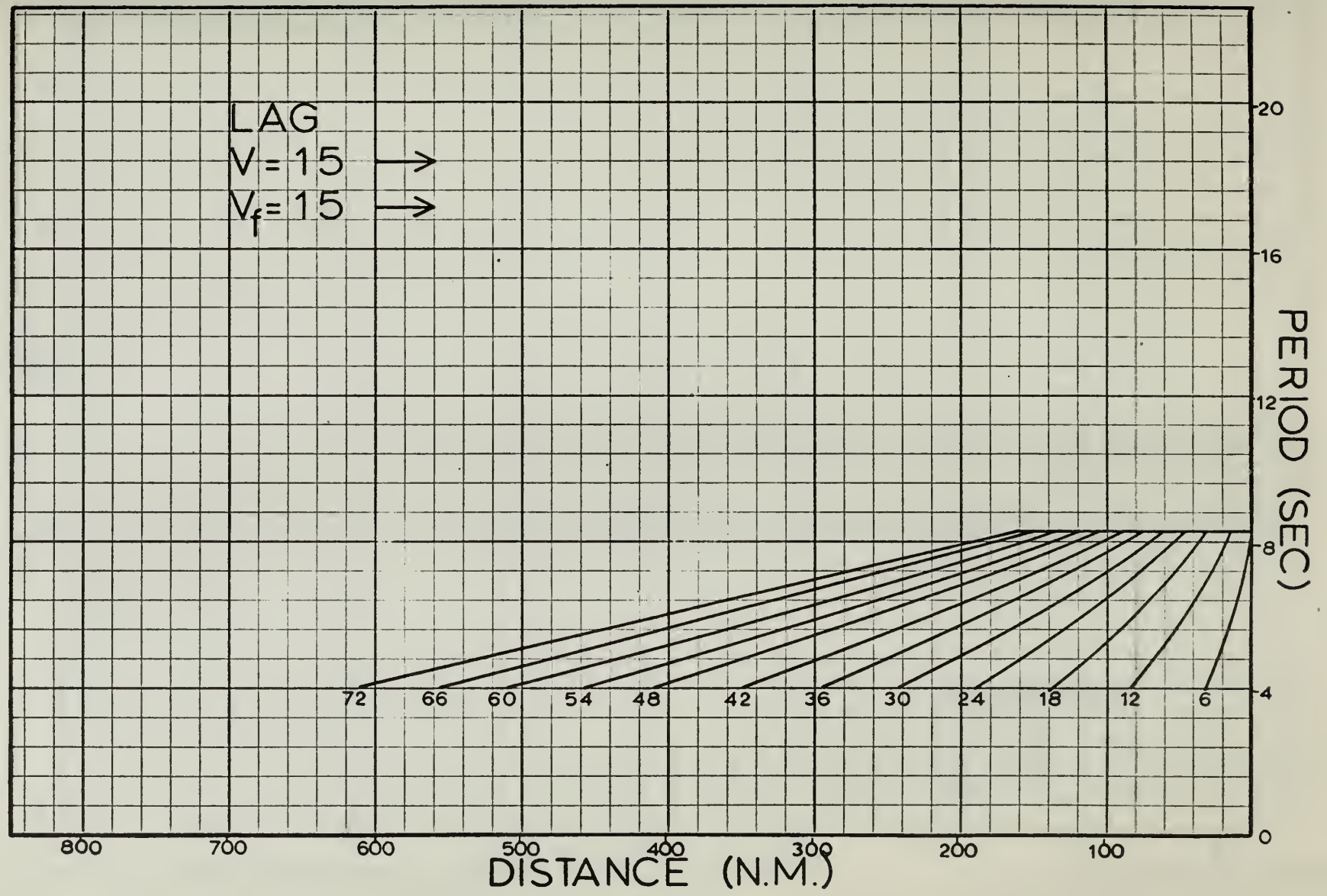



SWELL
V=55 →
PERIOD (SEC)
24
20
16
12
8
4
6
12
18
24
30
36
42
48
54
60
66
72
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

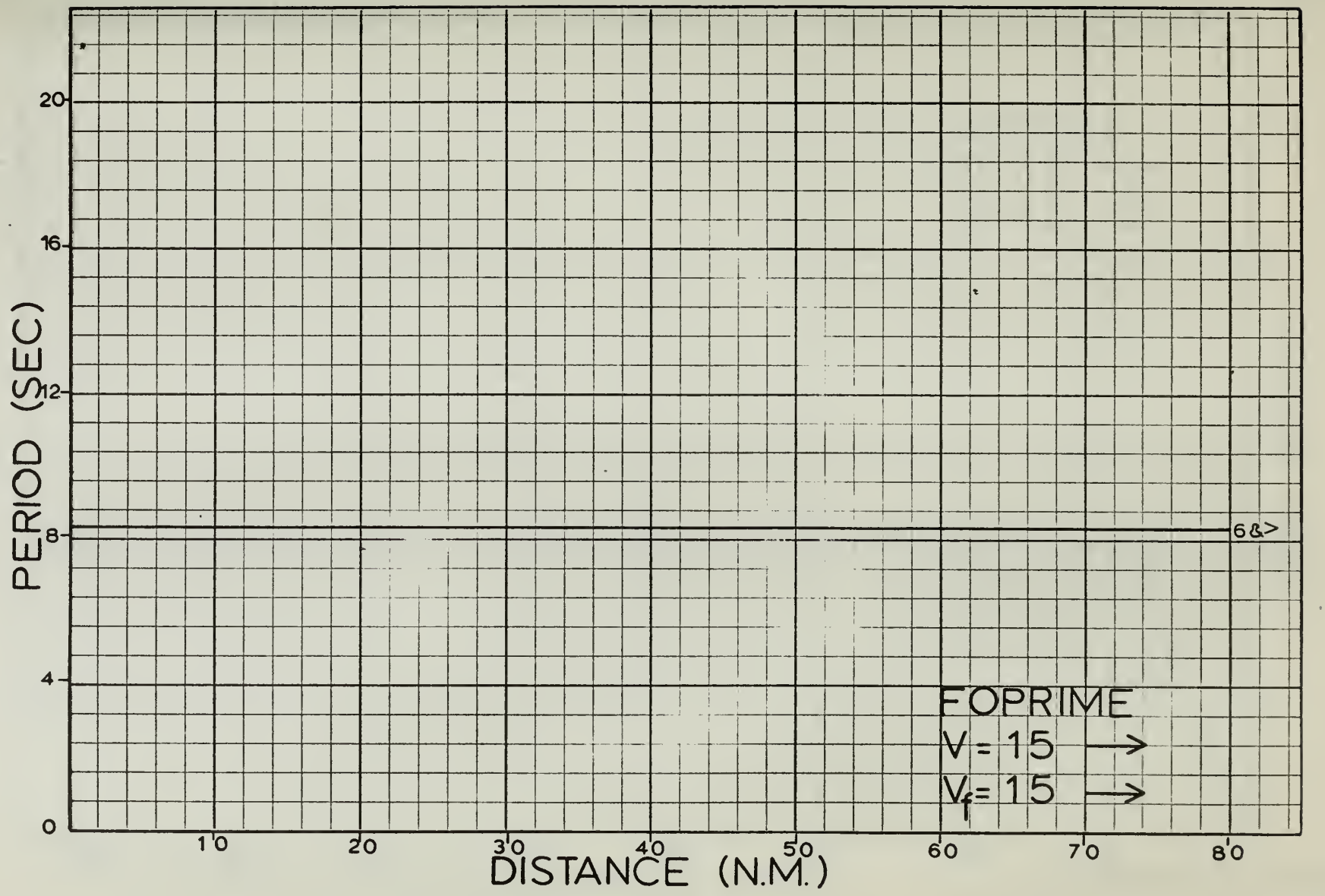
18.2 Moving (leeward) Fetch Model Graphs

INDEX OF GRAPHS

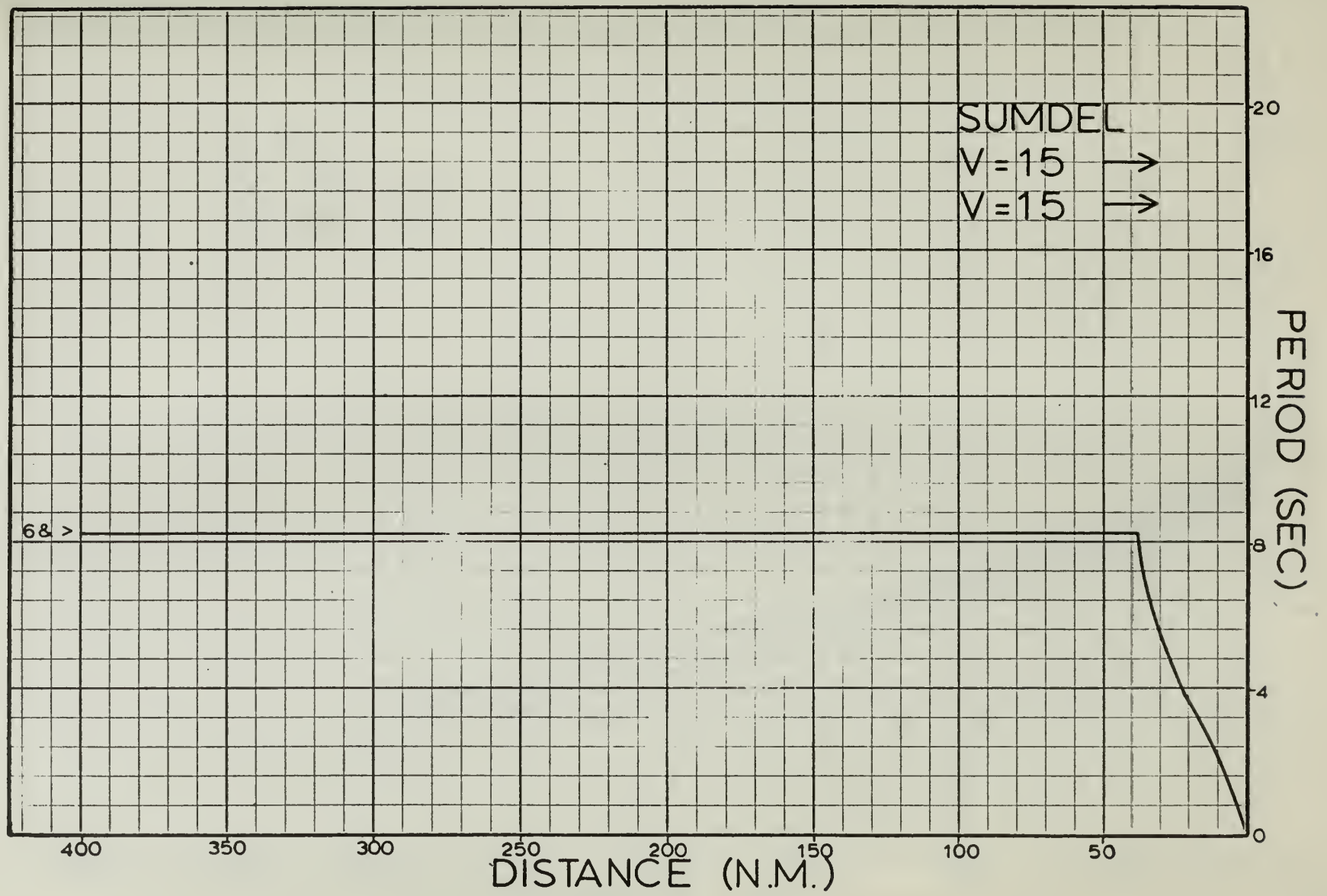
Wind Speed (V)	Fetch Speed (V_f)	Inclusive Pages
15	15	64-66
20	15	67-70
	20	71-73
25	15	74-77
	20	78-80
	25	81-83
30	15	84-87
	20	88-91
	25	92-94
	30	95-97
35	15	98-101
	20	102-105
	25	106-108
	30	109-111
	35	112-114
40	15	115-118
	20	119-122
	25	123-125
	30	126-128
	35	129-131
	40	132-134
45	15	135-138
	20	139-142
	25	143-145
	30	146-148
	35	149-151
	40	152-154
	45	155-157
50	15	158-161
	20	162-165
	25	166-168
	30	169-171
	35	172-174
	40	175-177
	45	178-180
	50	181-183
55	15	184-187
	20	188-191
	25	192-194
	30	195-197
	35	198-200
	40	201-203
	45	204-206
	50	207-209
	55	210-212


LAG
V = 15 →
Vf = 15 →
72
66
60
54
48
42
36
30
24
18
12
6
800
700
600
500
400
300
200
100
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)

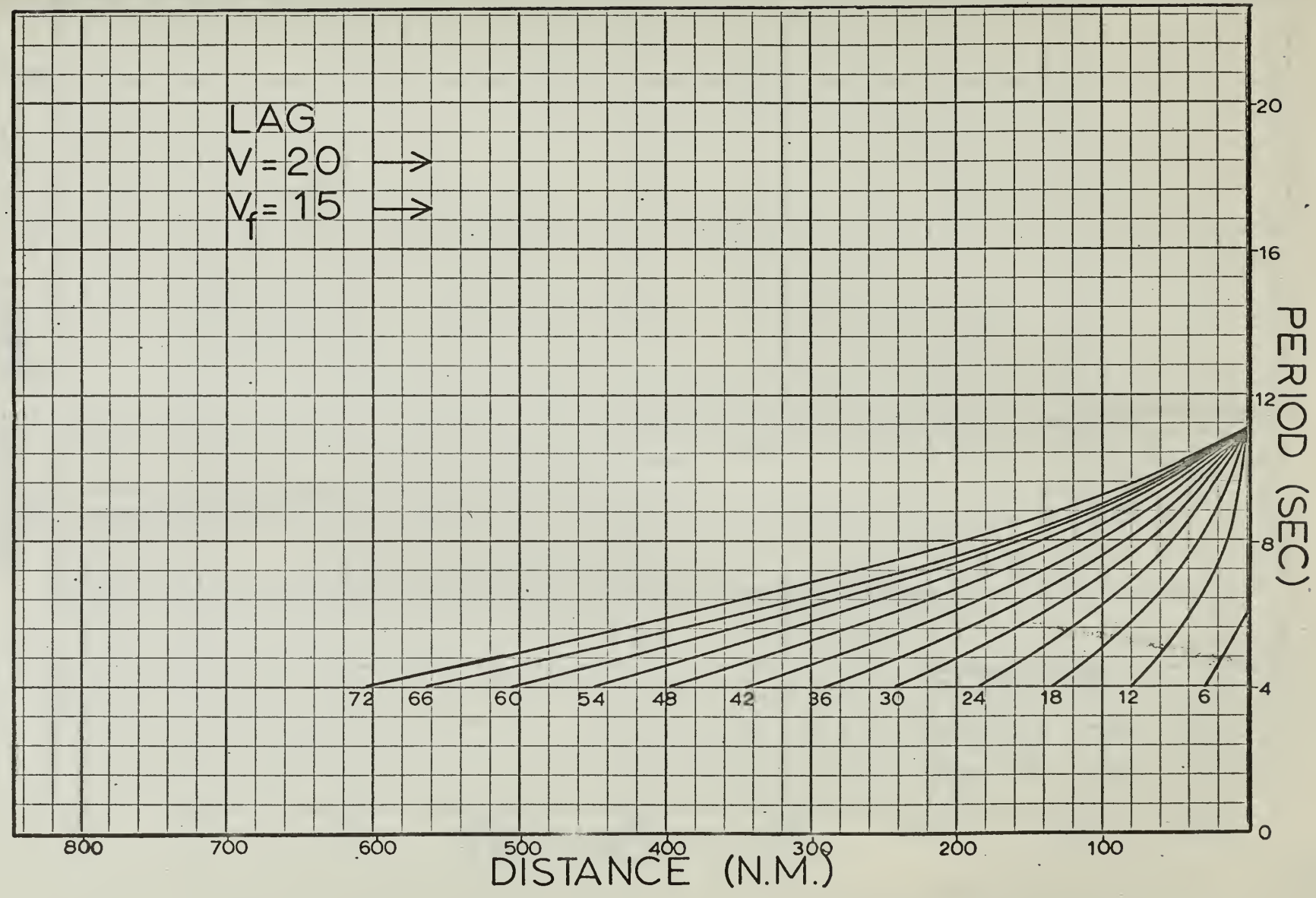



PERIOD (SEC)
0
4
8
12
16
20
68>
FOPRIME
V = 15
Vf = 15
10
20
30
40
50
60
70
80
DISTANCE (N.M.)

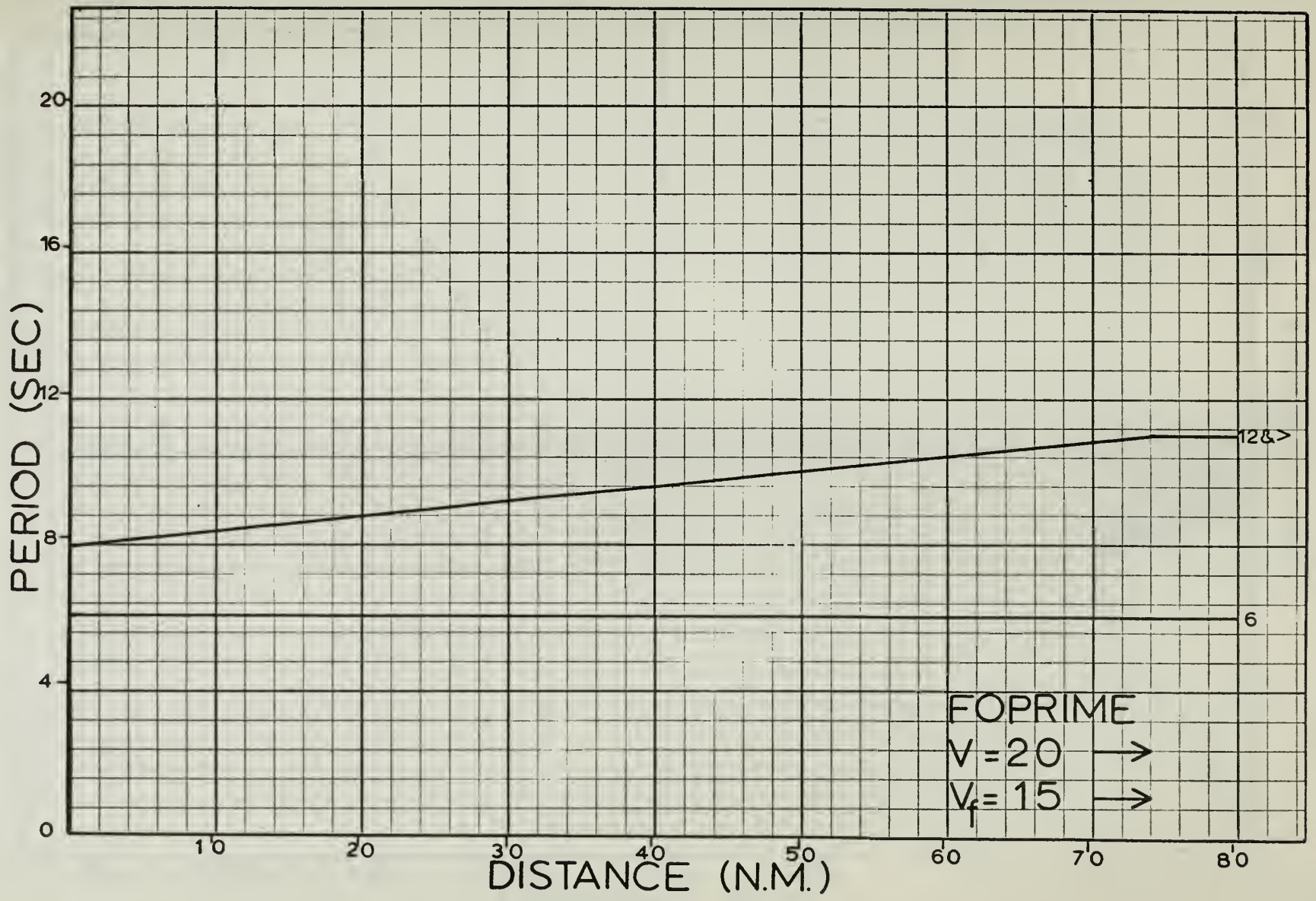


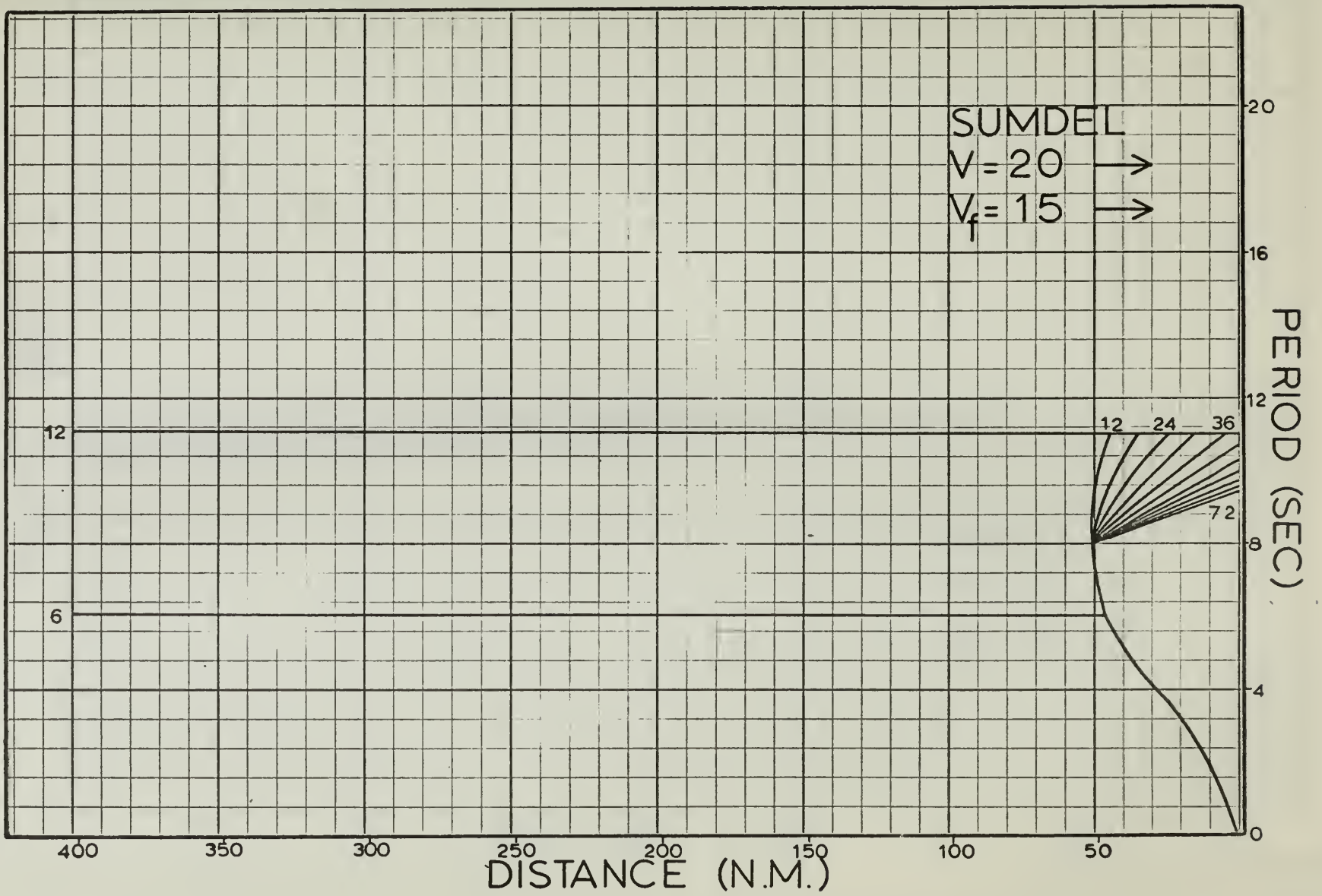

SUMDEL
V=15
V=15
6& >
20
16
12
8
4
0
PERIOD (SEC)
400
350
300
250
200
150
100
50
DISTANCE (N.M.)



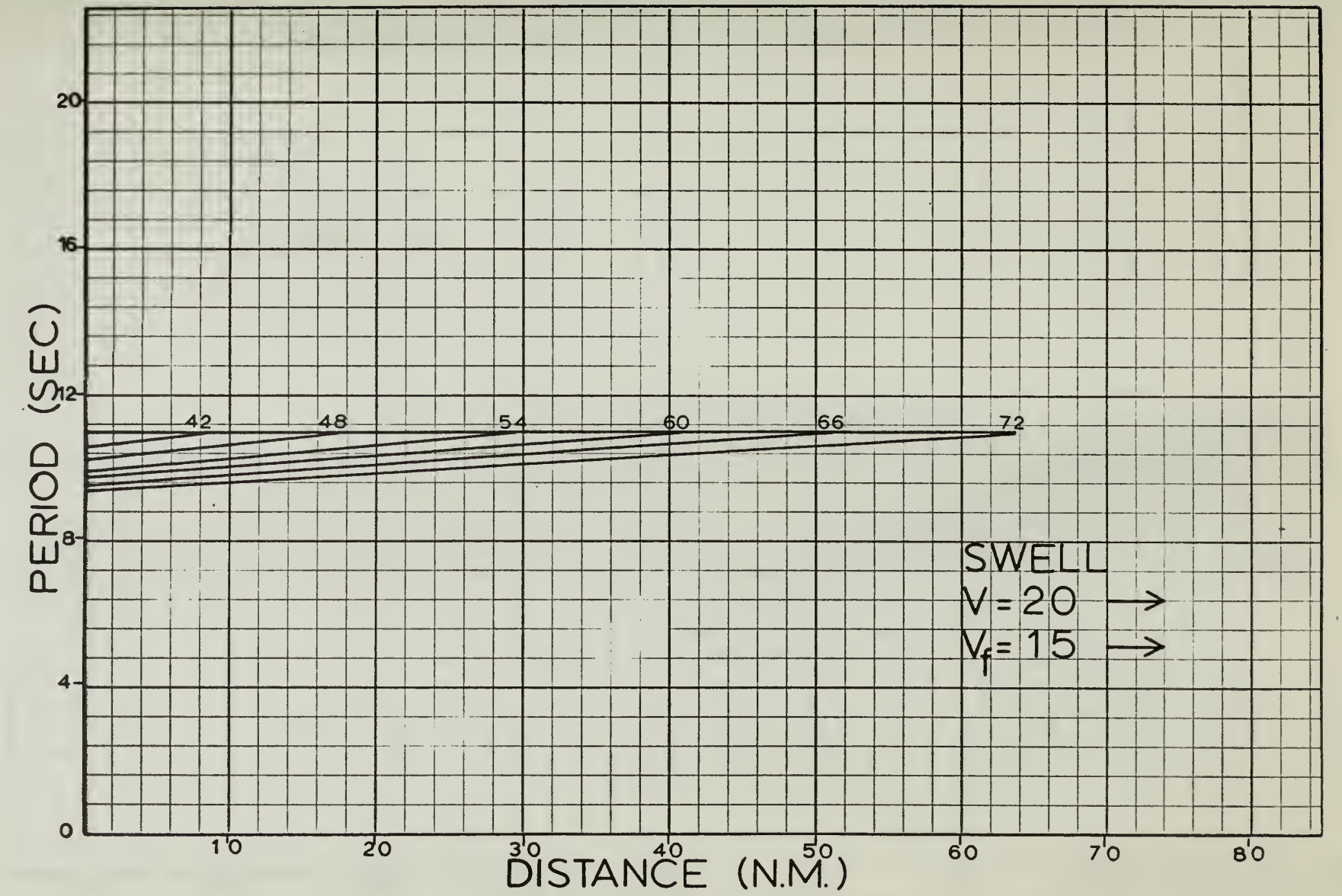

LAG
V = 20 →
V_f = 15 →
72
66
60
54
48
42
36
30
24
18
12
6
800
700
600
500
400
300
200
100
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)



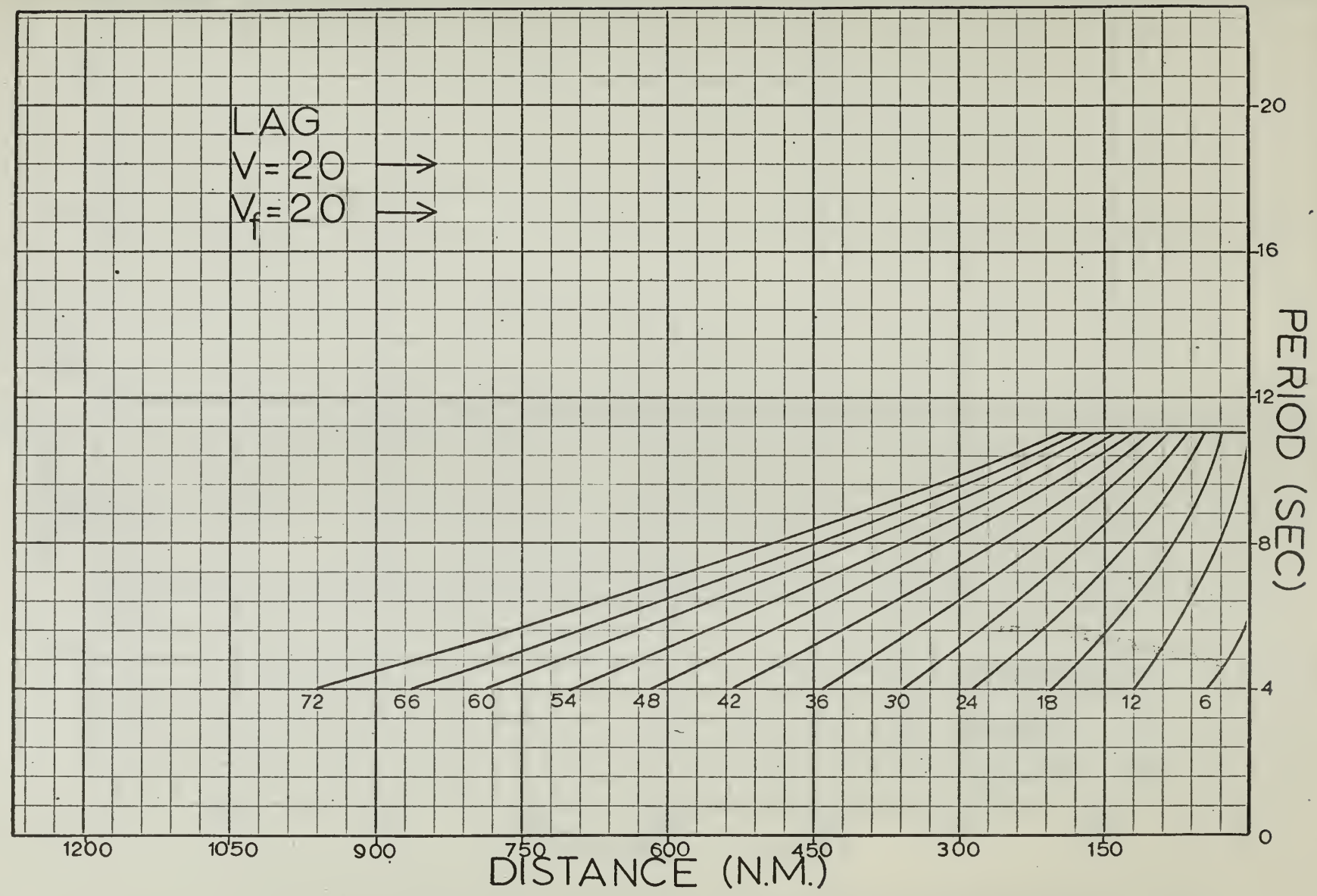

PERIOD (SEC)
0
4
8
12
16
20
1'0
2'0
3'0
4'0
5'0
6'0
7'0
8'0
DISTANCE (N.M.)
12δ>
6
FOPRIME
V = 20 →
Vf = 15 →

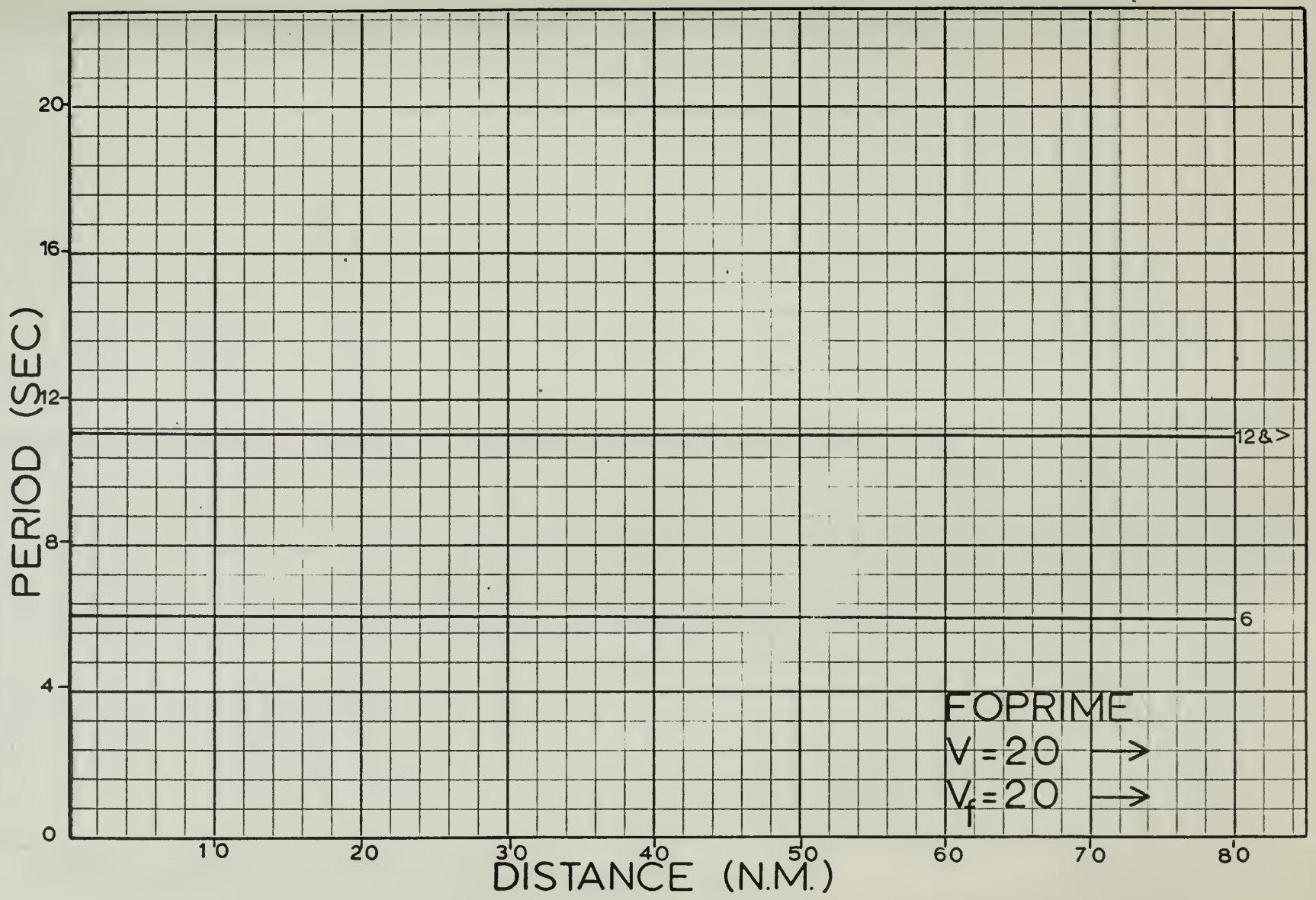

SUMDEL
V = 20
V_f = 15
12
24
36
72
12
6
20
16
12
8
4
0
PERIOD (SEC)
400
350
300
250
200
150
100
50
DISTANCE (N.M.)



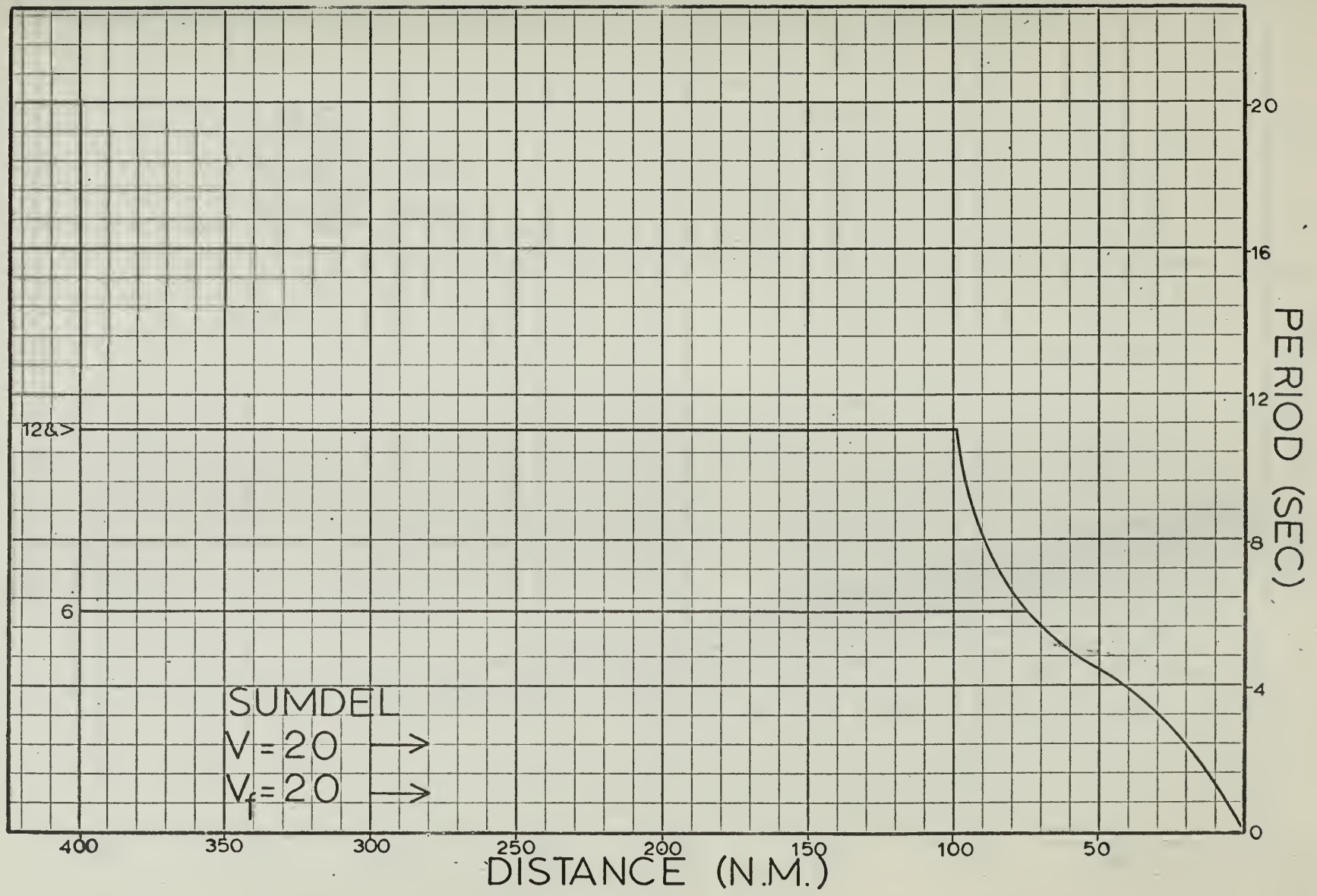

PERIOD (SEC)
20
16
12
8
4
0
42
48
54
60
66
72
SWELL
V = 20 →
Vf = 15 →
1'0
2'0
3'0
4'0
5'0
6'0
7'0
8'0
DISTANCE (N.M.)



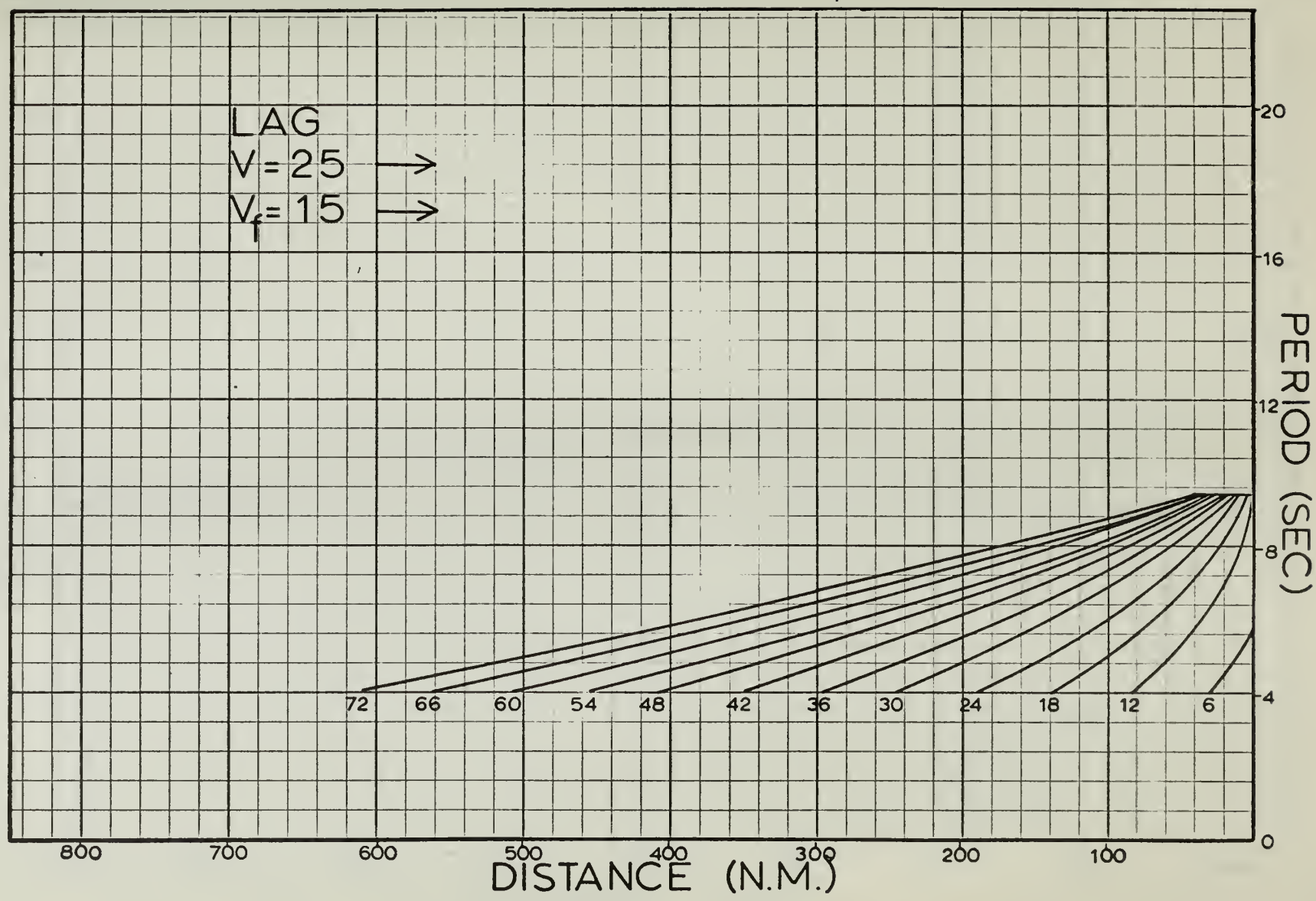

LAG
V = 20 →
V_f = 20 →
72
66
60
54
48
42
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
1200
1050
900
750
600
450
300
150
DISTANCE (N.M.)


PERIOD (SEC)
0
4
8
12
16
20
12&>
6
FOPRIME
V=20 →
V_f=20 →
1'0
20
3'0
40
50
60
70
8'0
DISTANCE (N.M.)

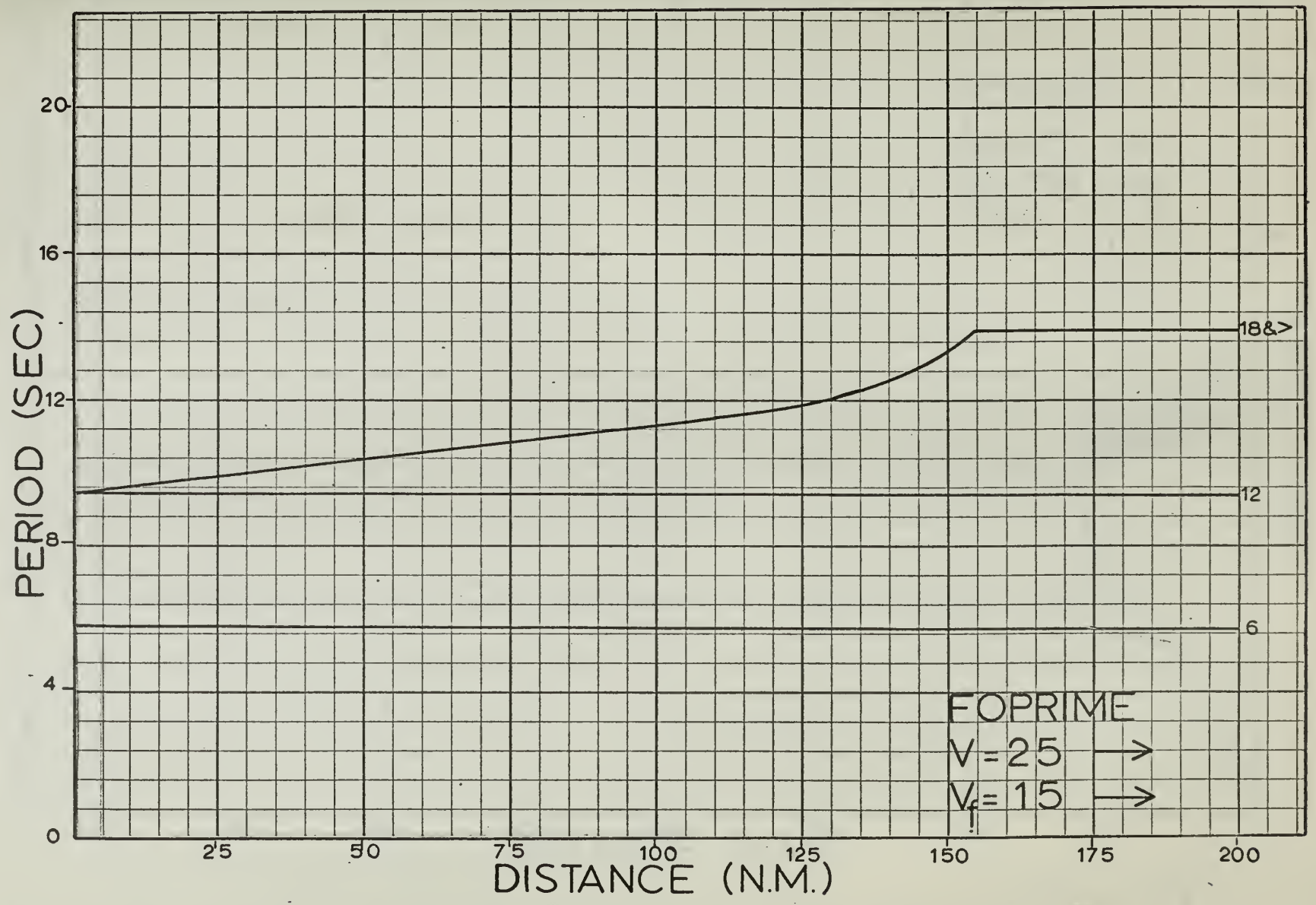


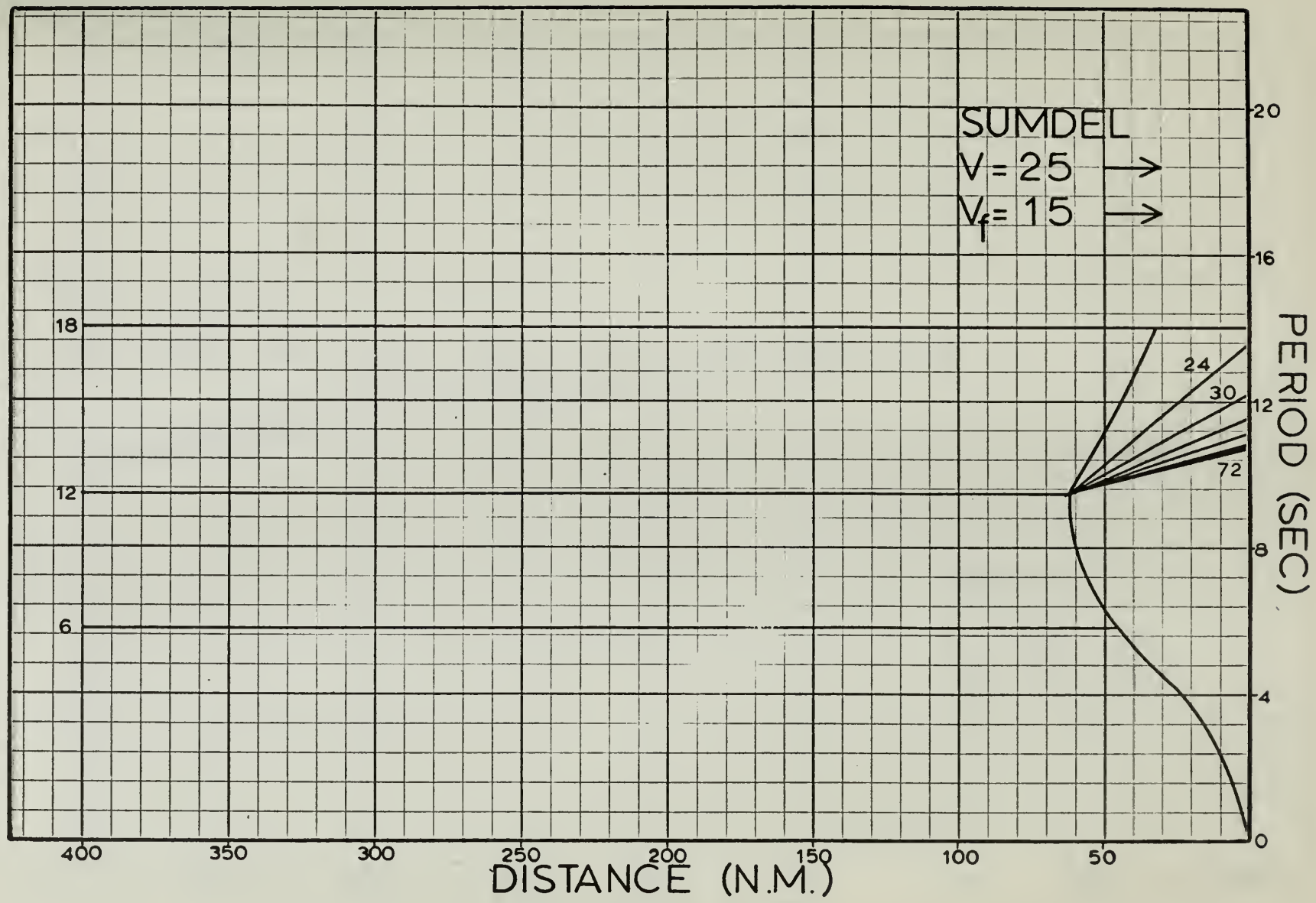

PERIOD (SEC)
20
16
12
8
4
0
12&>
6
SUMDEL
V = 20 →
Vf = 20 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)



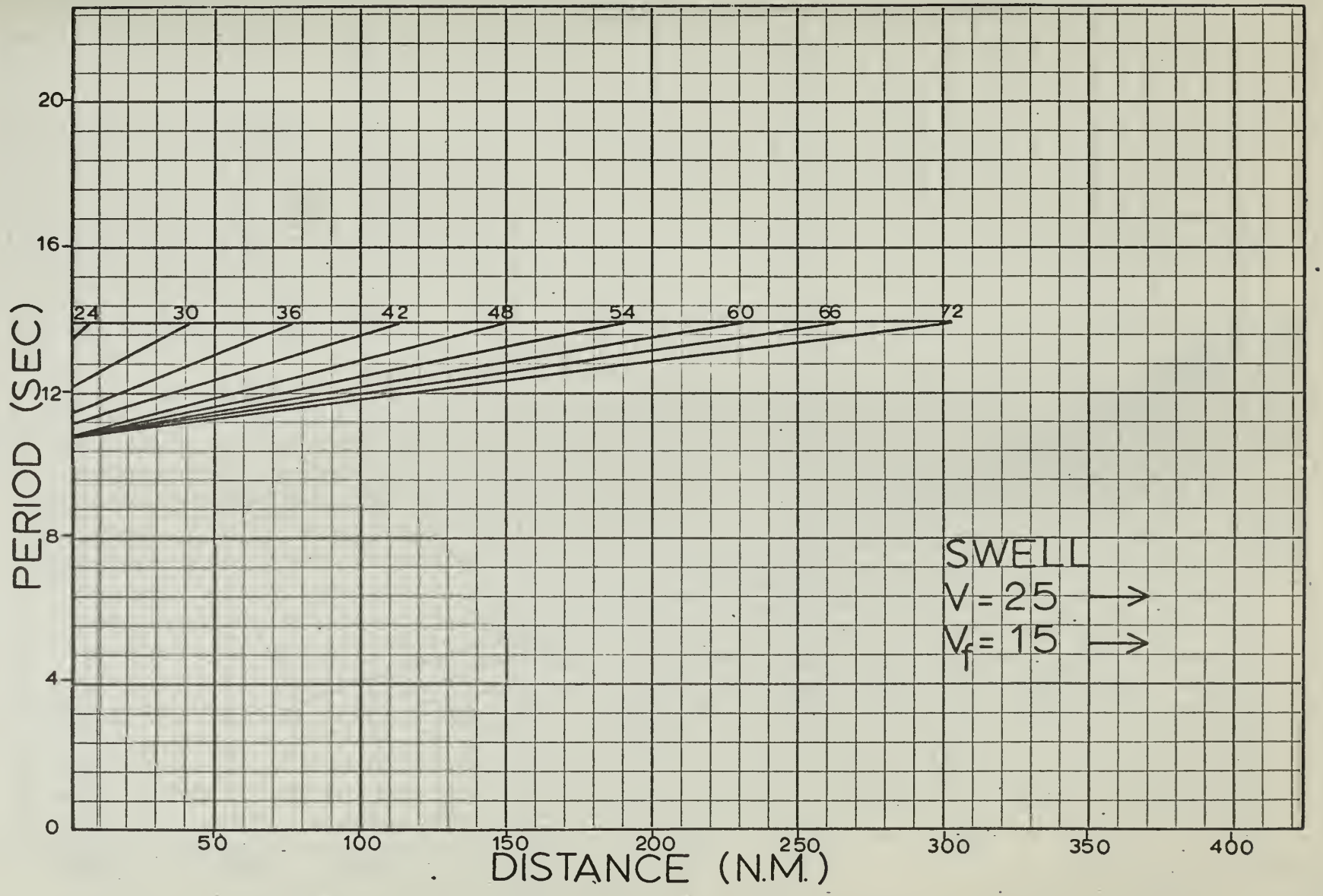

LAG
V = 25 →
Vf = 15 →
72
66
60
54
48
42
36
30
24
18
12
6
800
700
600
500
400
300
200
100
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)

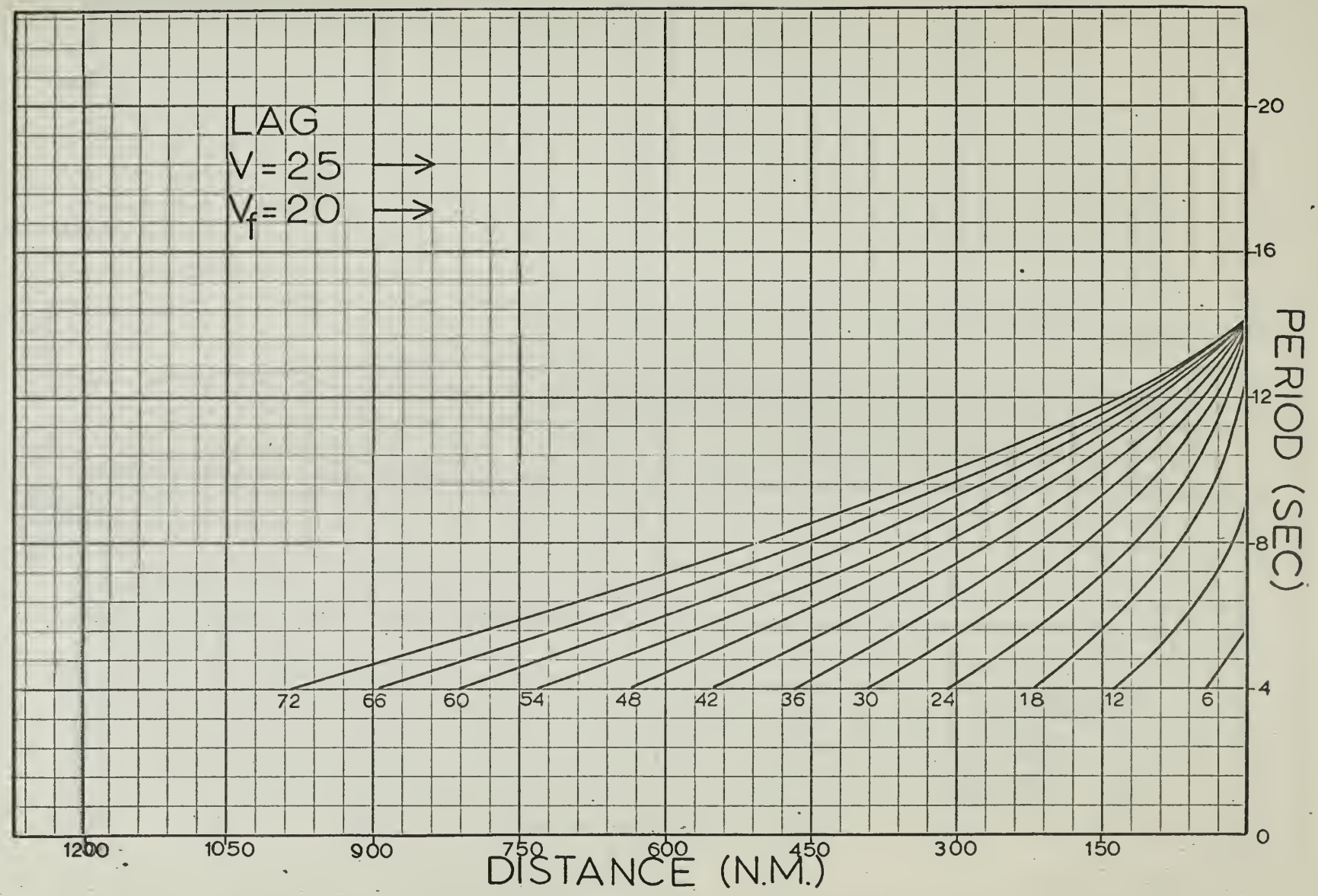


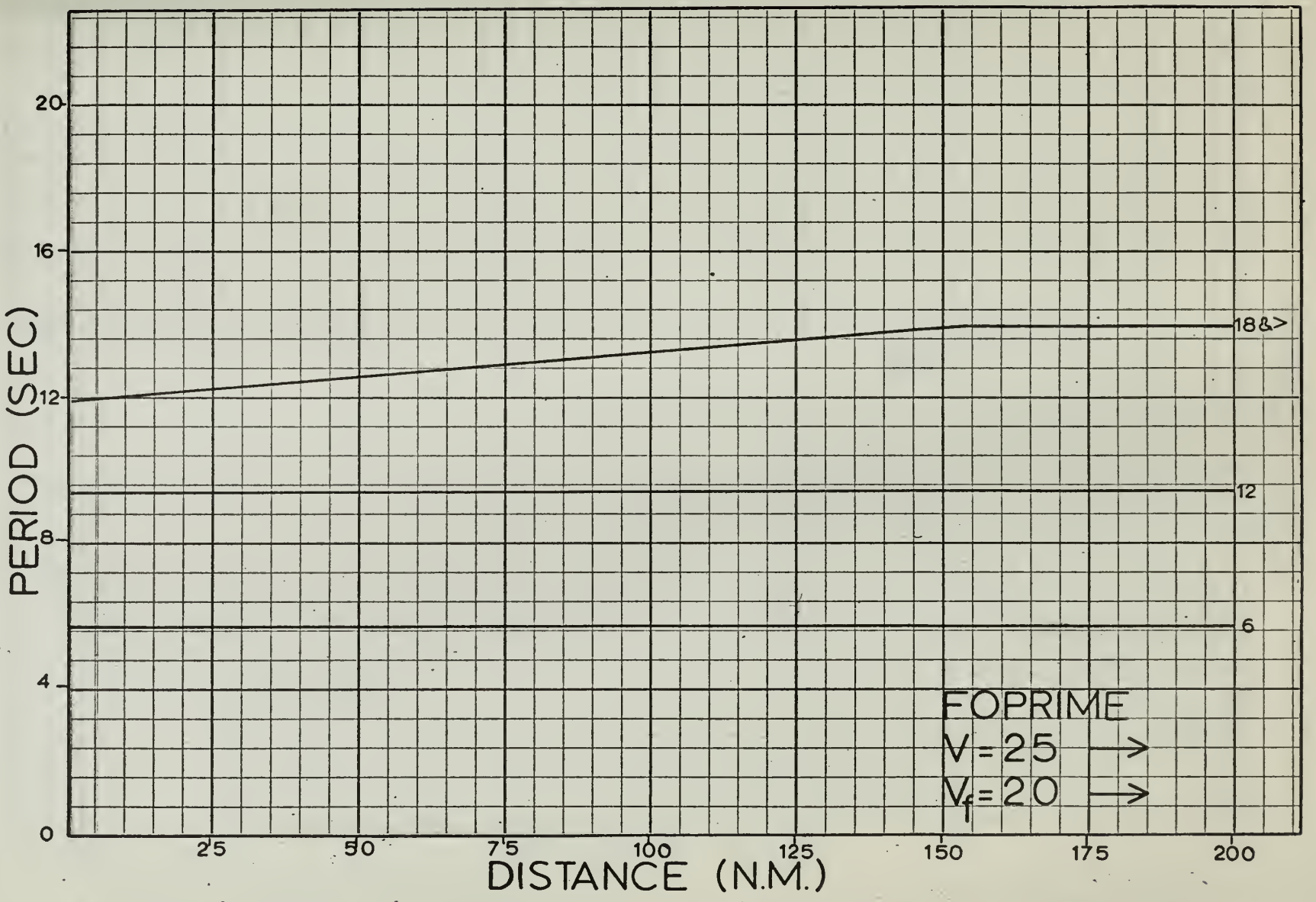

PERIOD (SEC)
20
16
12
8
4
0
18&>
12
6
FOPRIME
V = 25 →
Vf = 15 →
25
50
75
100
125
150
175
200
DISTANCE (N.M.)


SUMDEL
V = 25 →
Vf = 15 →
24
30
72
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
400
350
300
250
200
150
100
50
DISTANCE (N.M.)

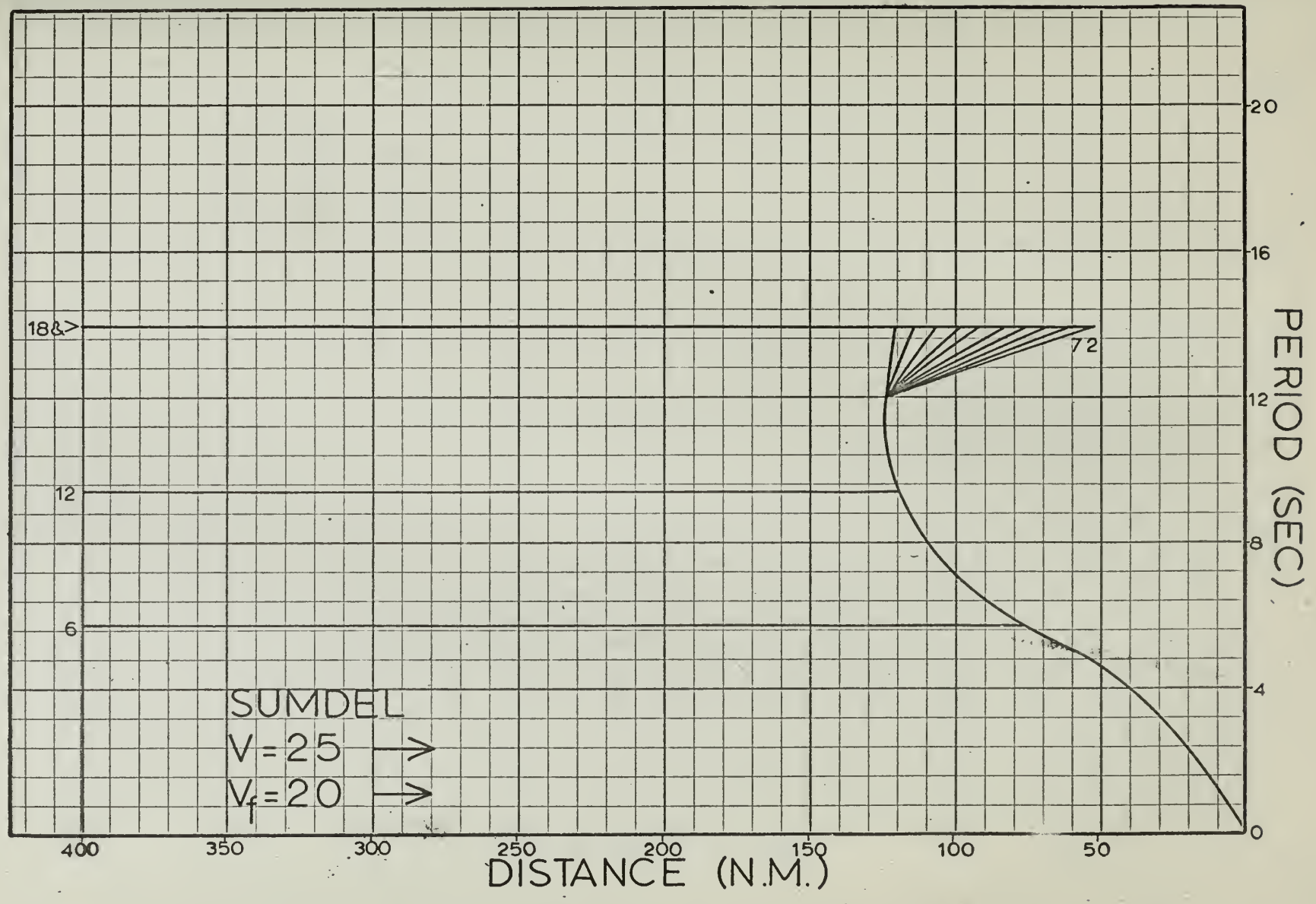


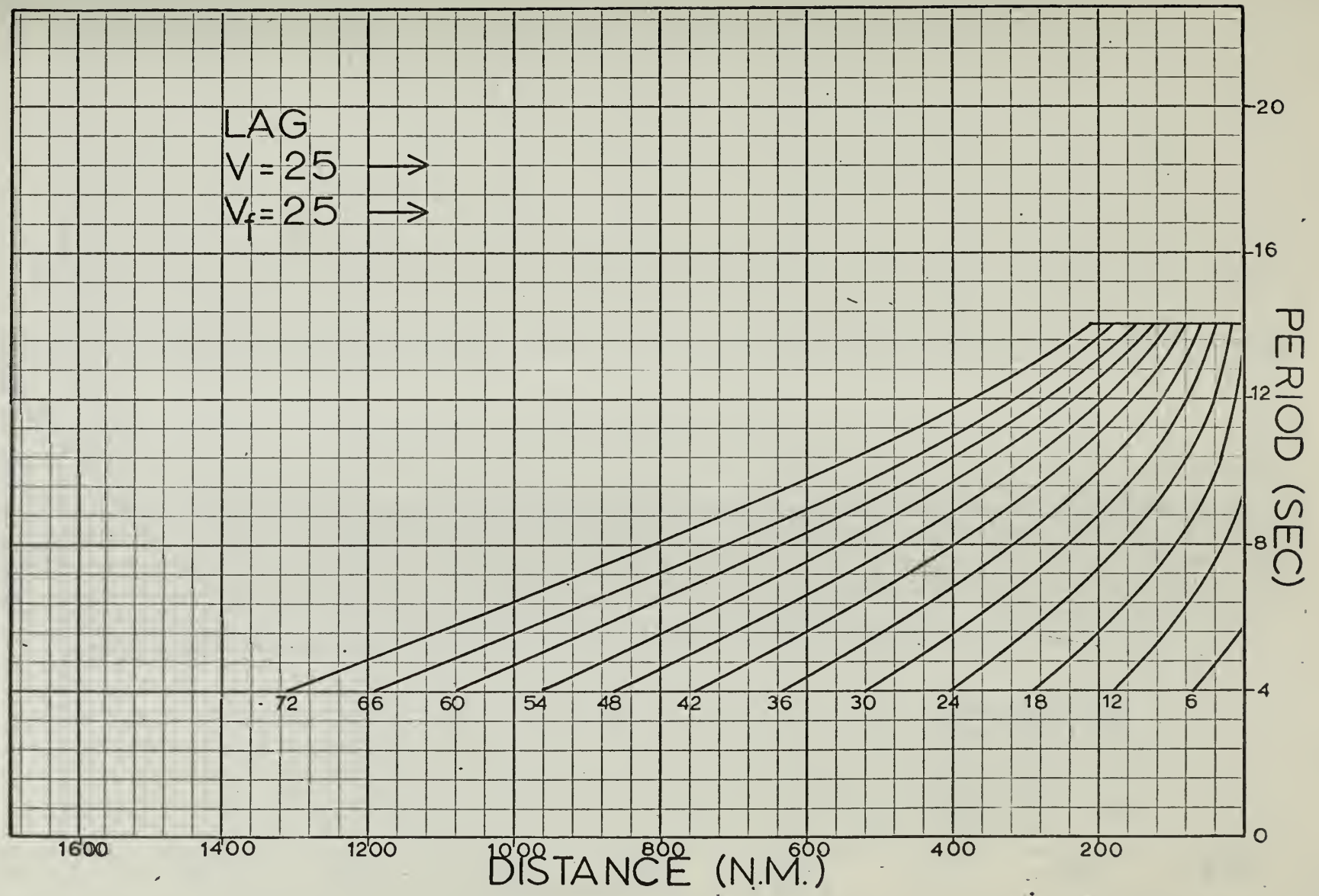

PERIOD (SEC)
20
16
12
8
4
0
24
30
36
42
48
54
60
66
72
SWELL
V = 25
Vf = 15
50
100
150
200
250
300
350
400
DISTANCE (N.M.)


LAG
V = 25
V_f = 20
72
66
60
54
48
42
36
30
24
18
12
6
1200
1050
900
750
600
450
300
150
0
4
8
12
16
20
DISTANCE (N.M.)
PERIOD (SEC)

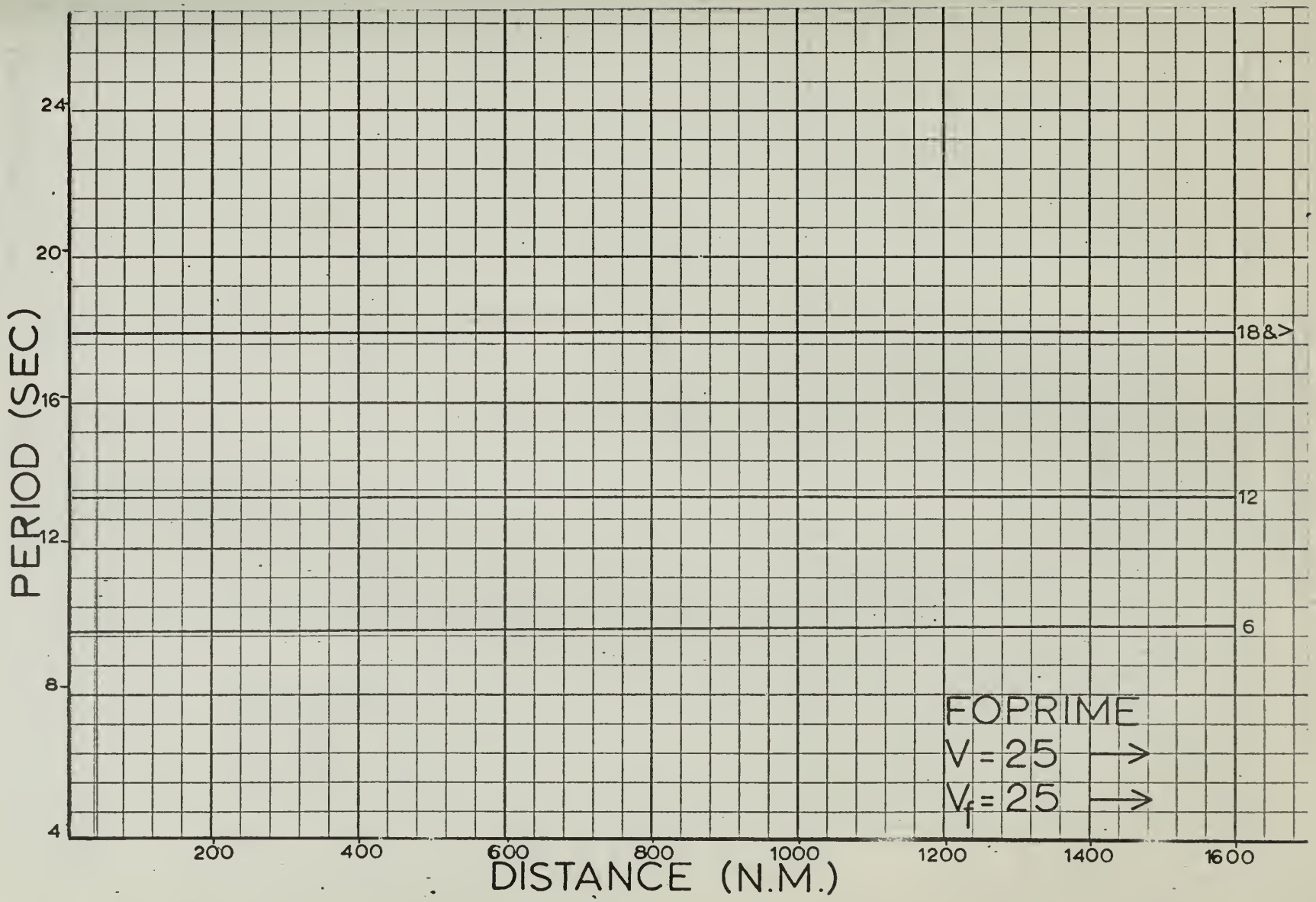

PERIOD (SEC)
0
4
8
12
16
20
25
50
75
100
125
150
175
200
DISTANCE (N.M.)
18&>
12
6
FOPRIME
V = 25 →
Vf = 20 →

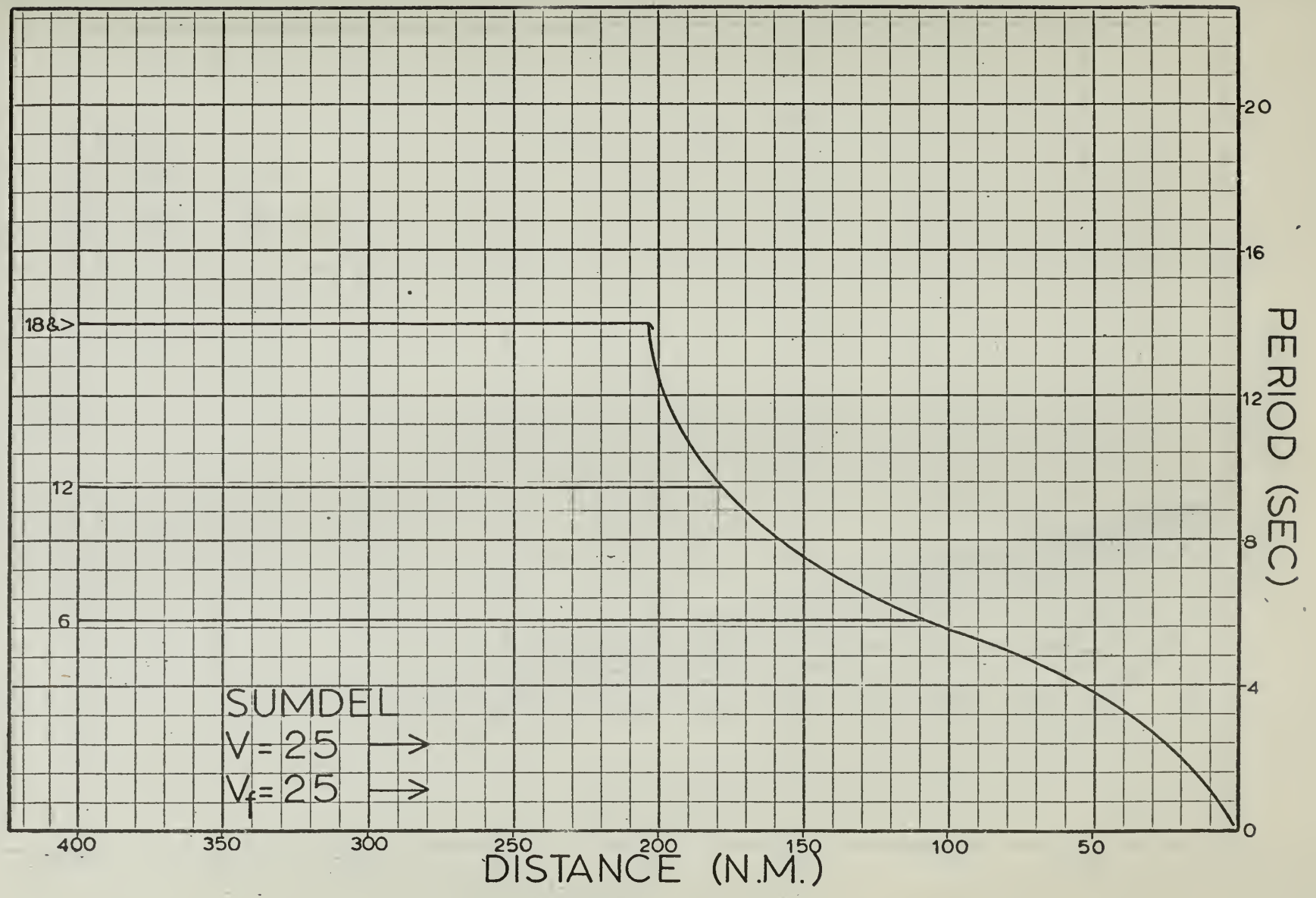


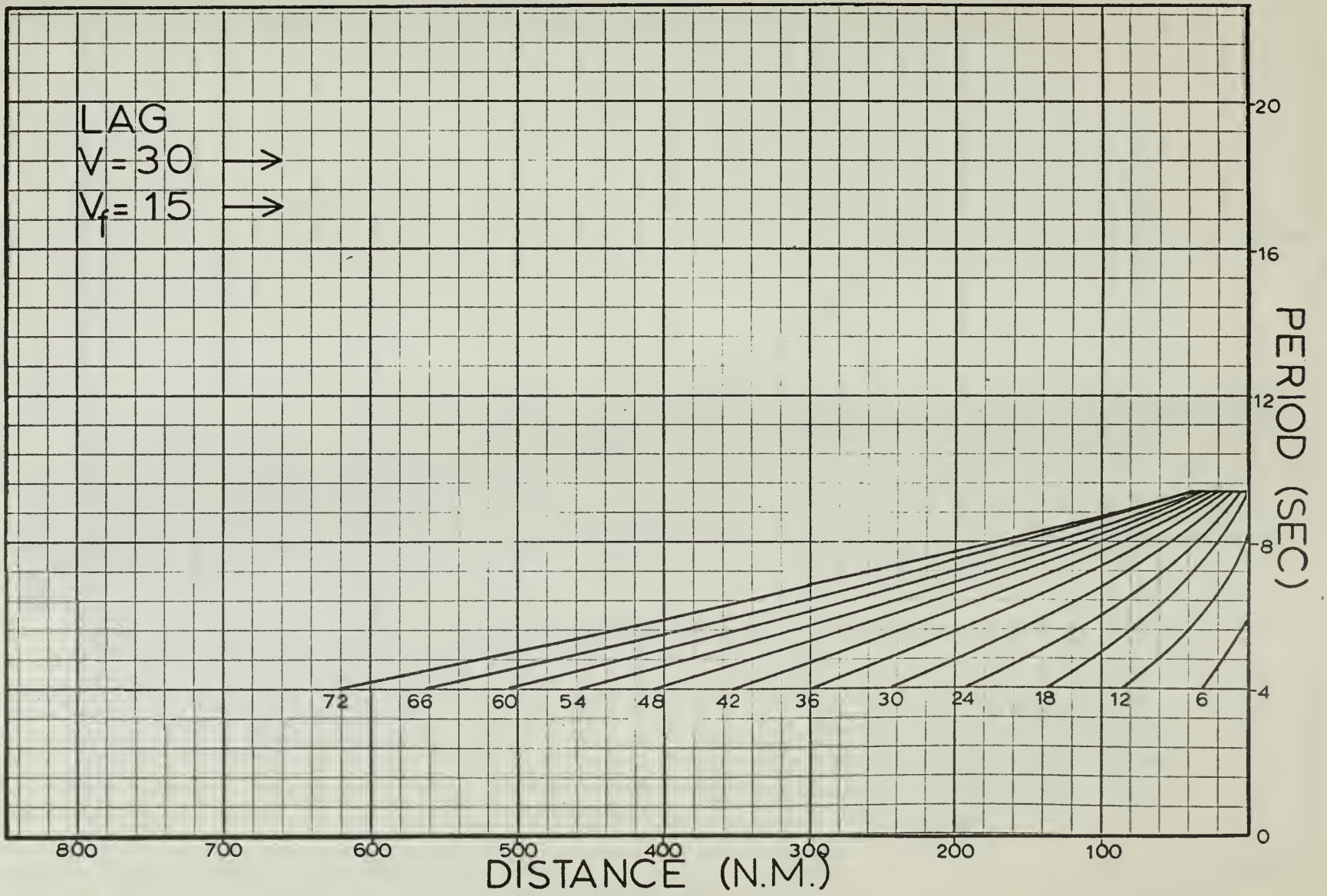

18&>
12
6
72
SUMDEL
V=25 →
Vf=20 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)

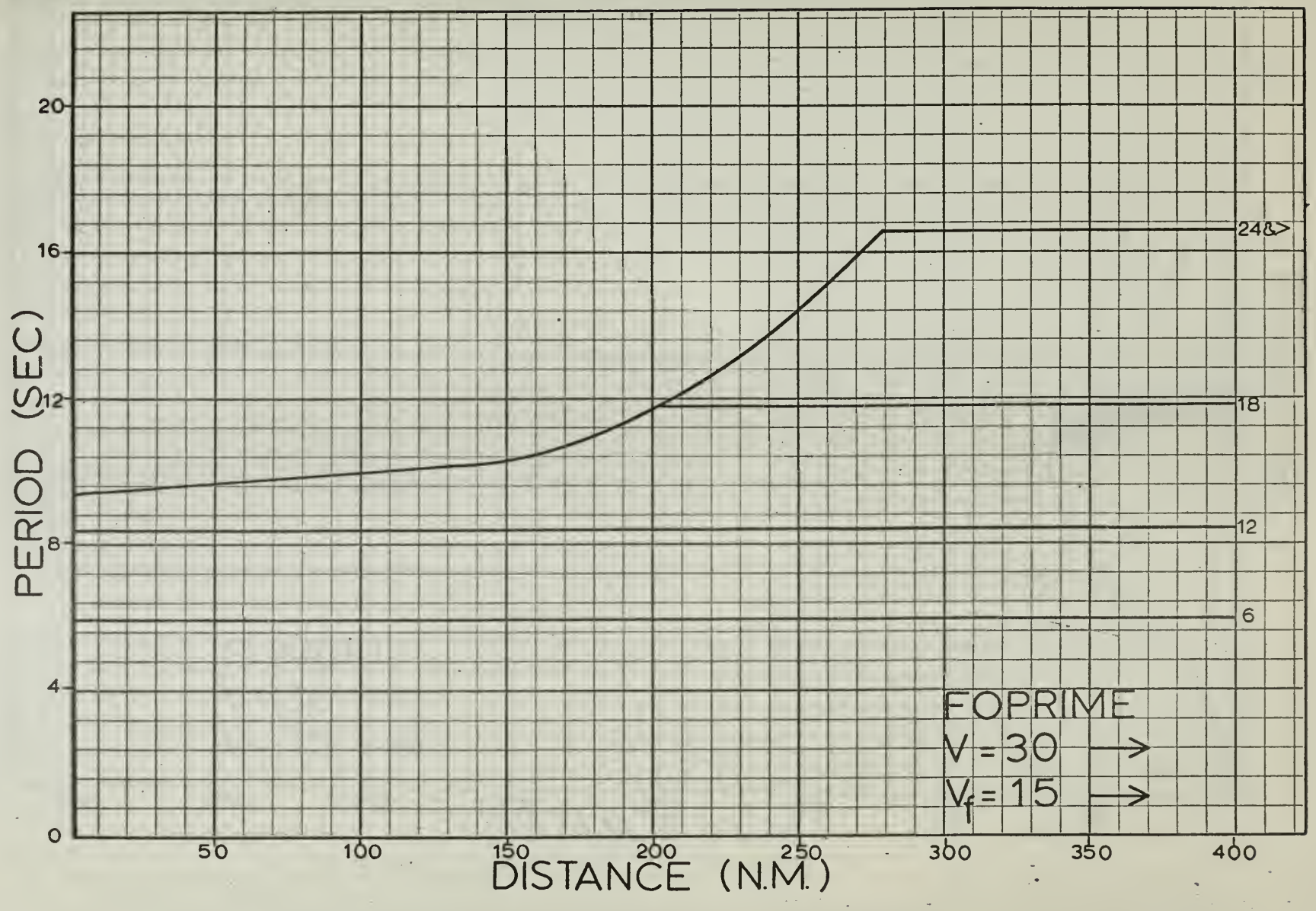

LAG
V = 25 →
Vf = 25 →
72
66
60
54
48
42
36
30
24
18
12
6
1600
1400
1200
1000
800
600
400
200
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)



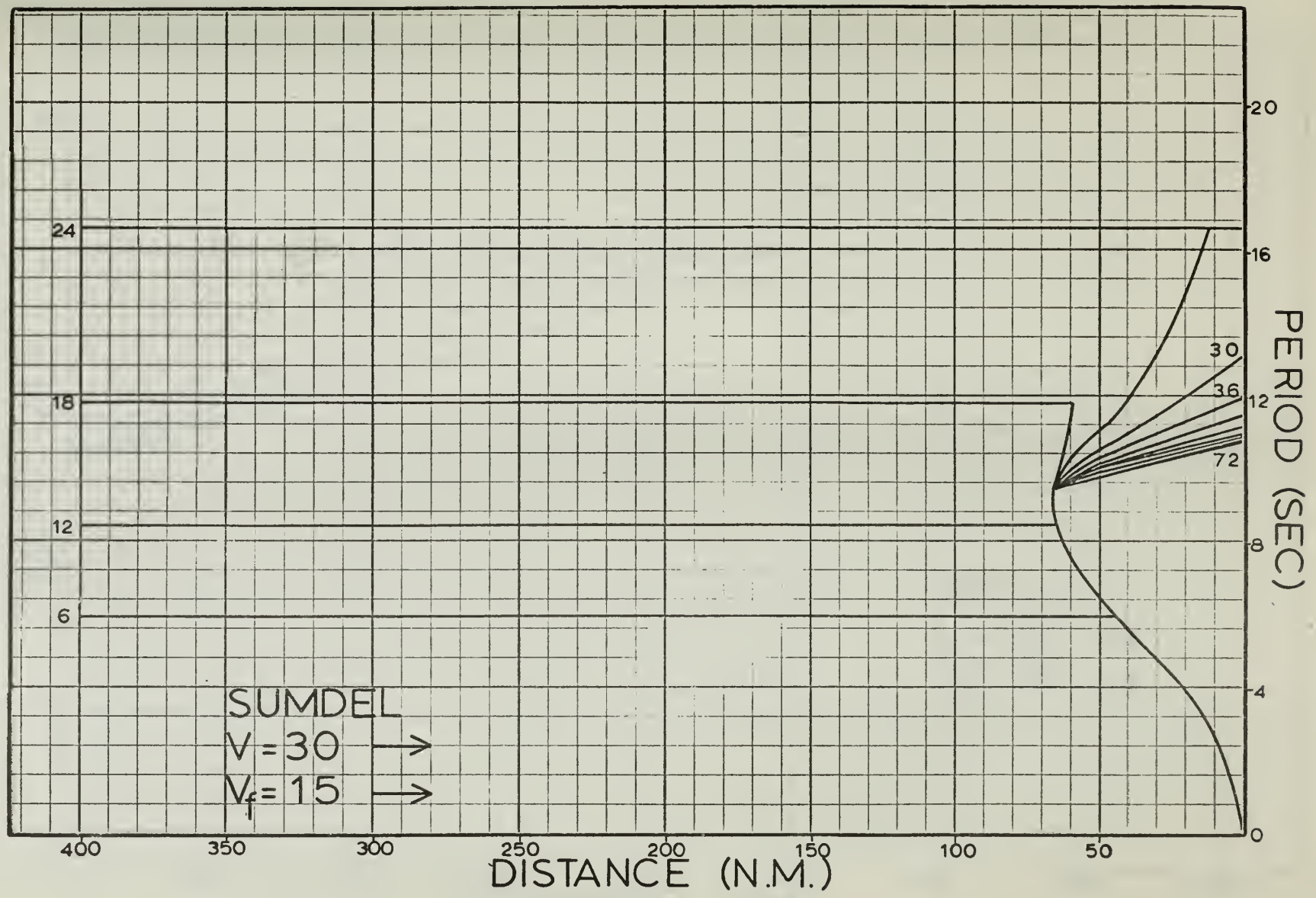

PERIOD (SEC)
24
20
16
12
8
4
18&>
12
6
FOPRIME
V = 25
V_f = 25
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)


18&>
12
6
SUMDEL
V = 25
Vf = 25
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)

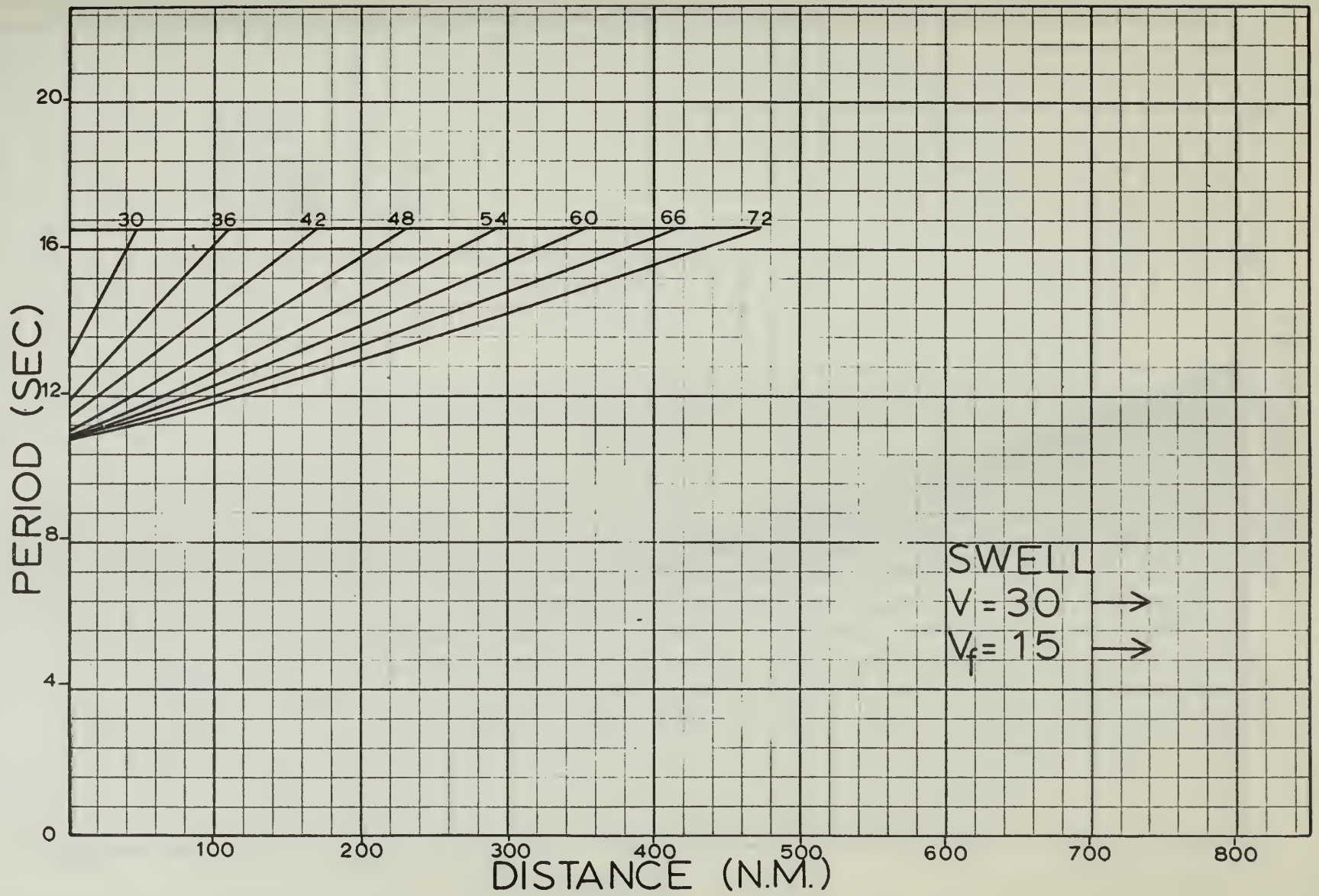

LAG
V = 30 →
V_f = 15 →
72
66
60
54
48
42
36
30
24
18
12
6
800
700
600
500
400
300
200
100
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)


PERIOD (SEC)
0
4
8
12
16
20
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
24&>
18
12
6
FOPRIME
V = 30
Vf = 15

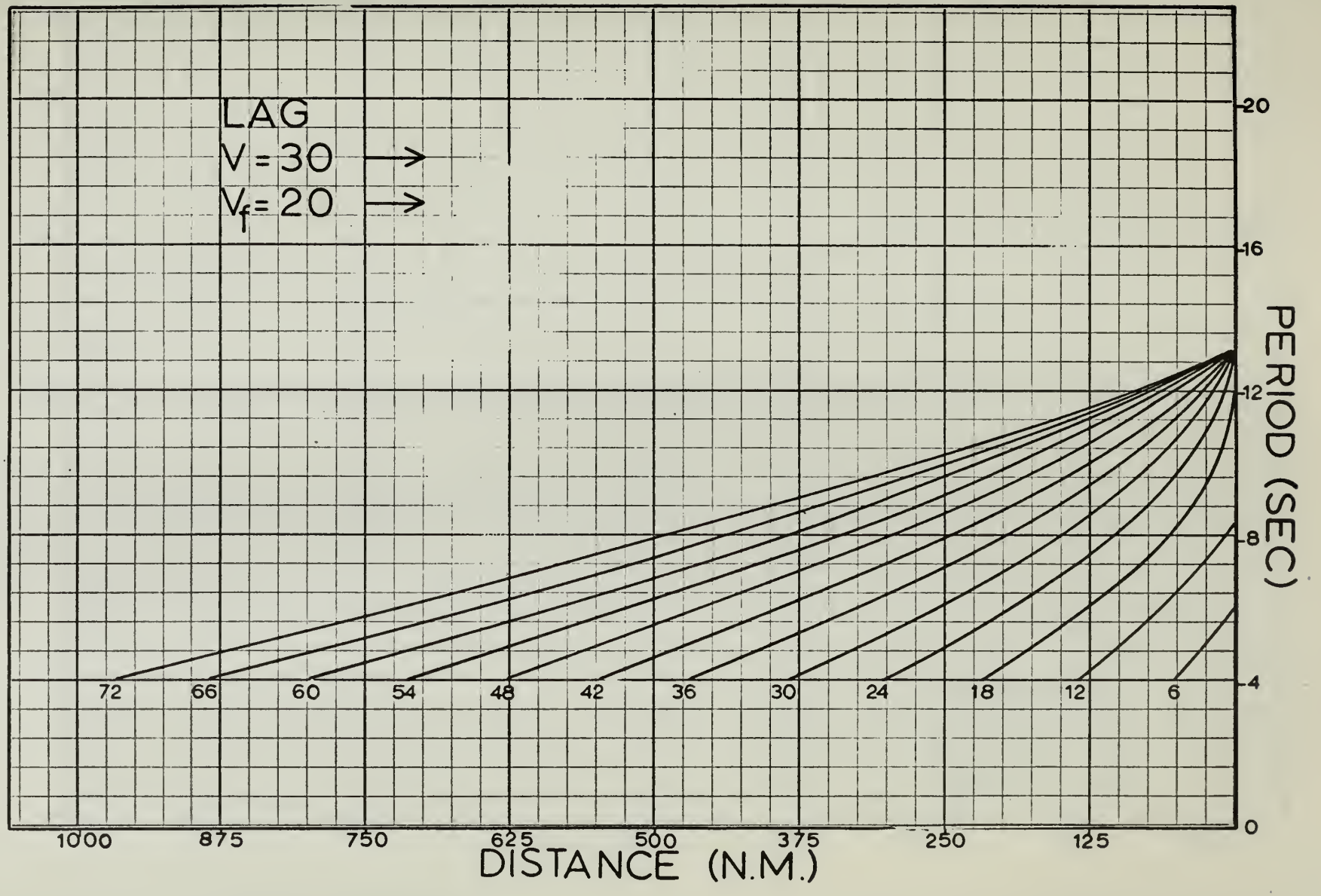



24
18
12
6
SUMDEL
V = 30 →
Vf = 15 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)
30
36
72

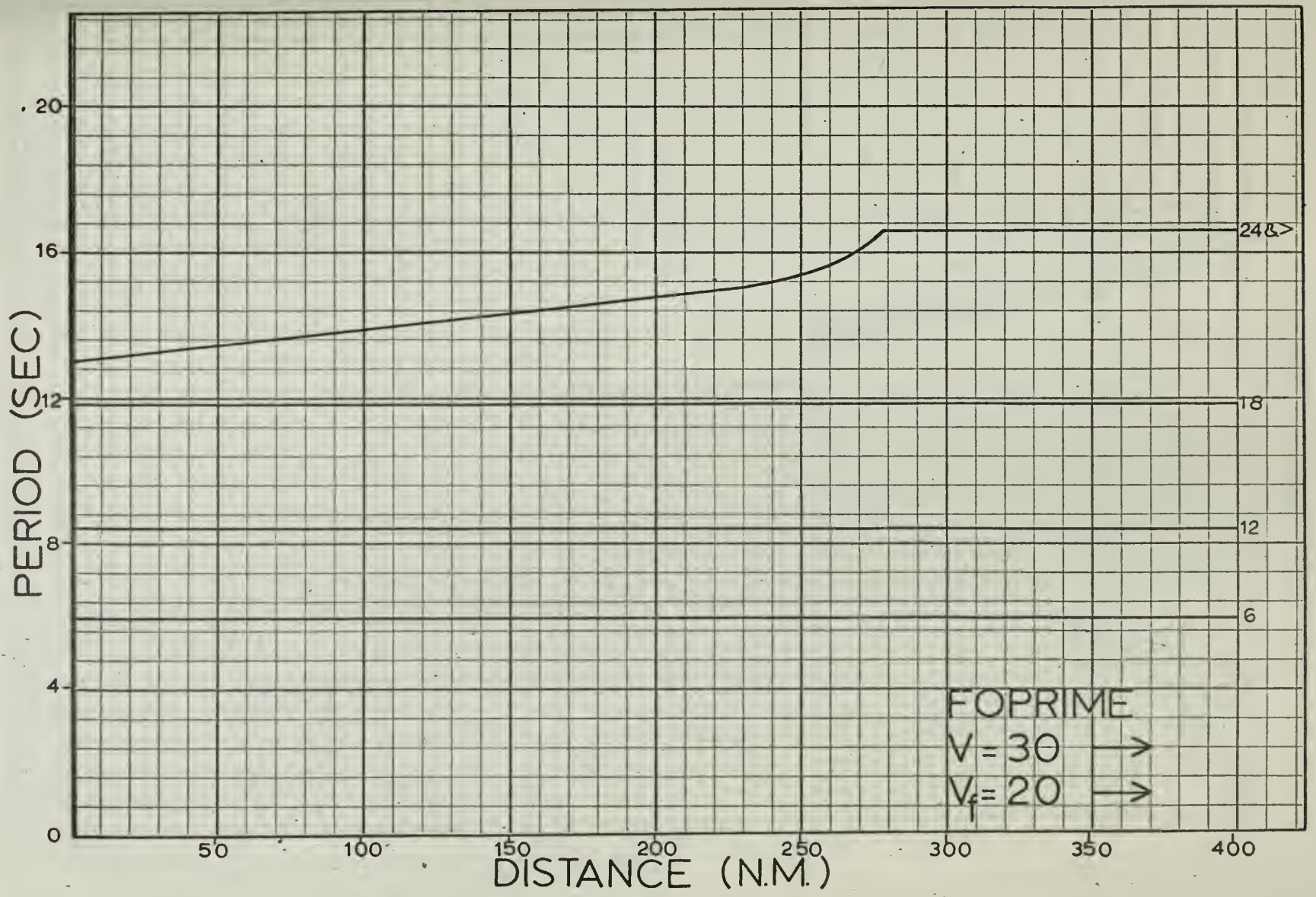


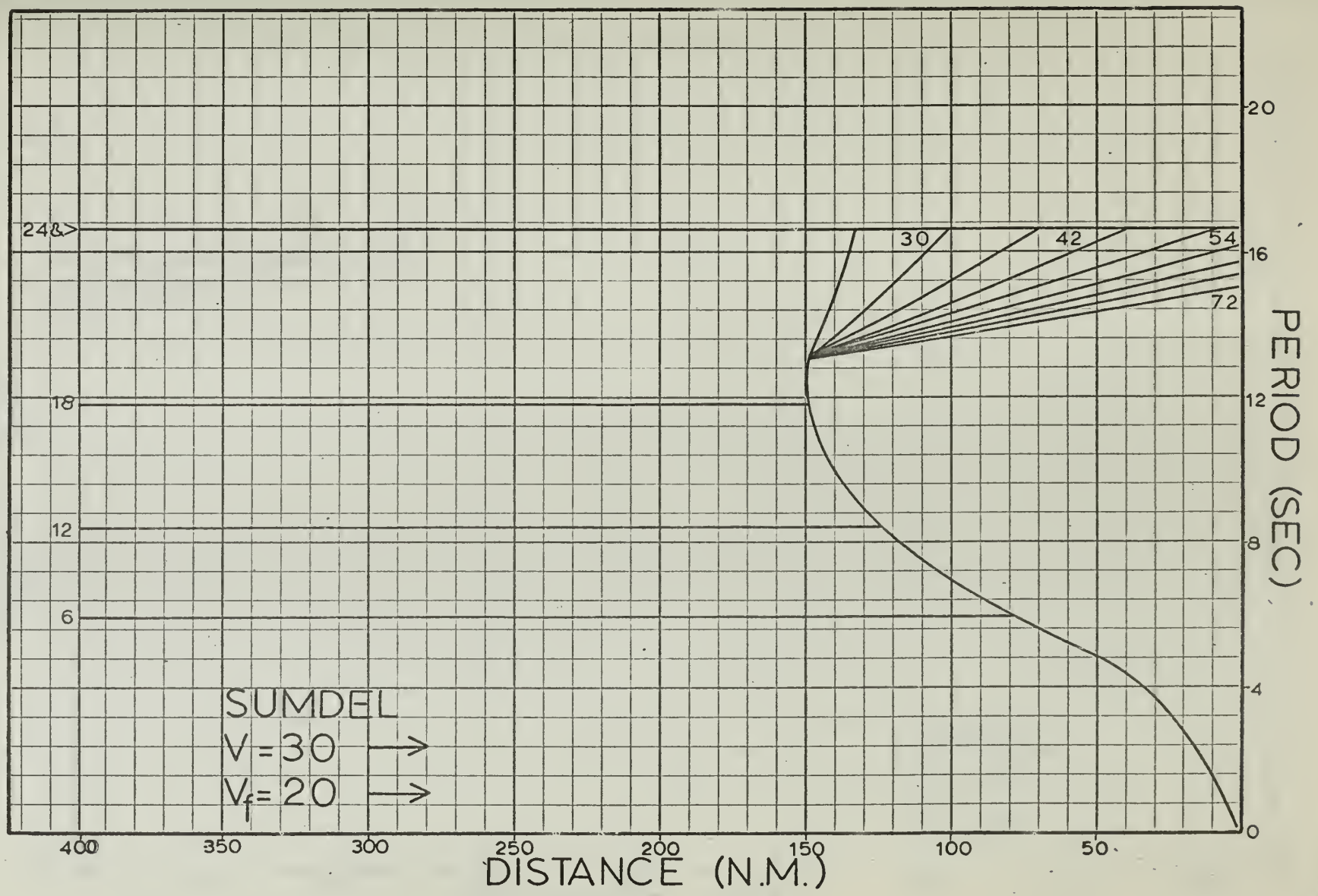

PERIOD (SEC)
0
4
8
12
16
20
30
36
42
48
54
60
66
72
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
SWELL
V = 30 →
Vf = 15 →

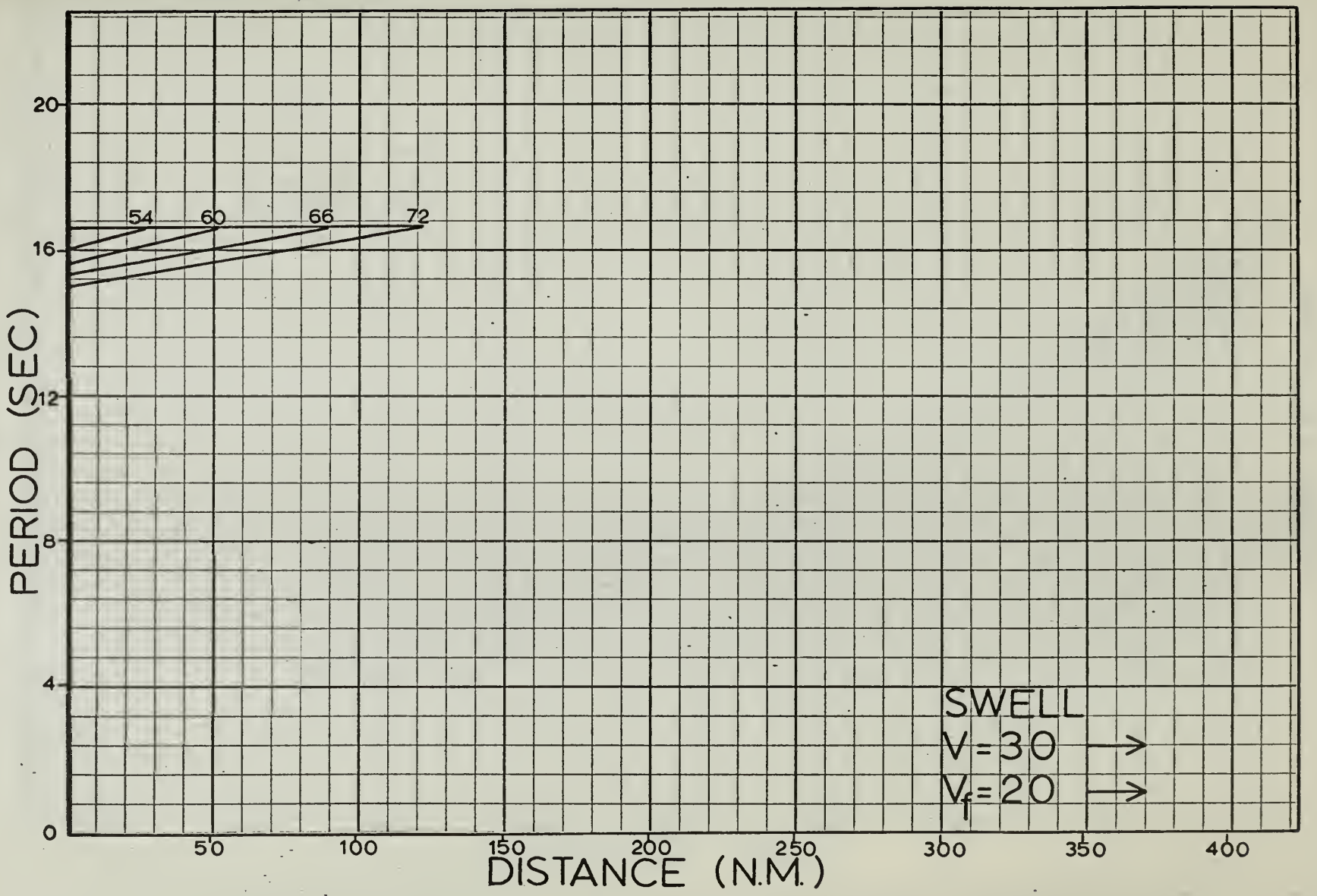



LAG
V = 30
V_f = 20
72
66
60
54
48
42
36
30
24
18
12
6
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

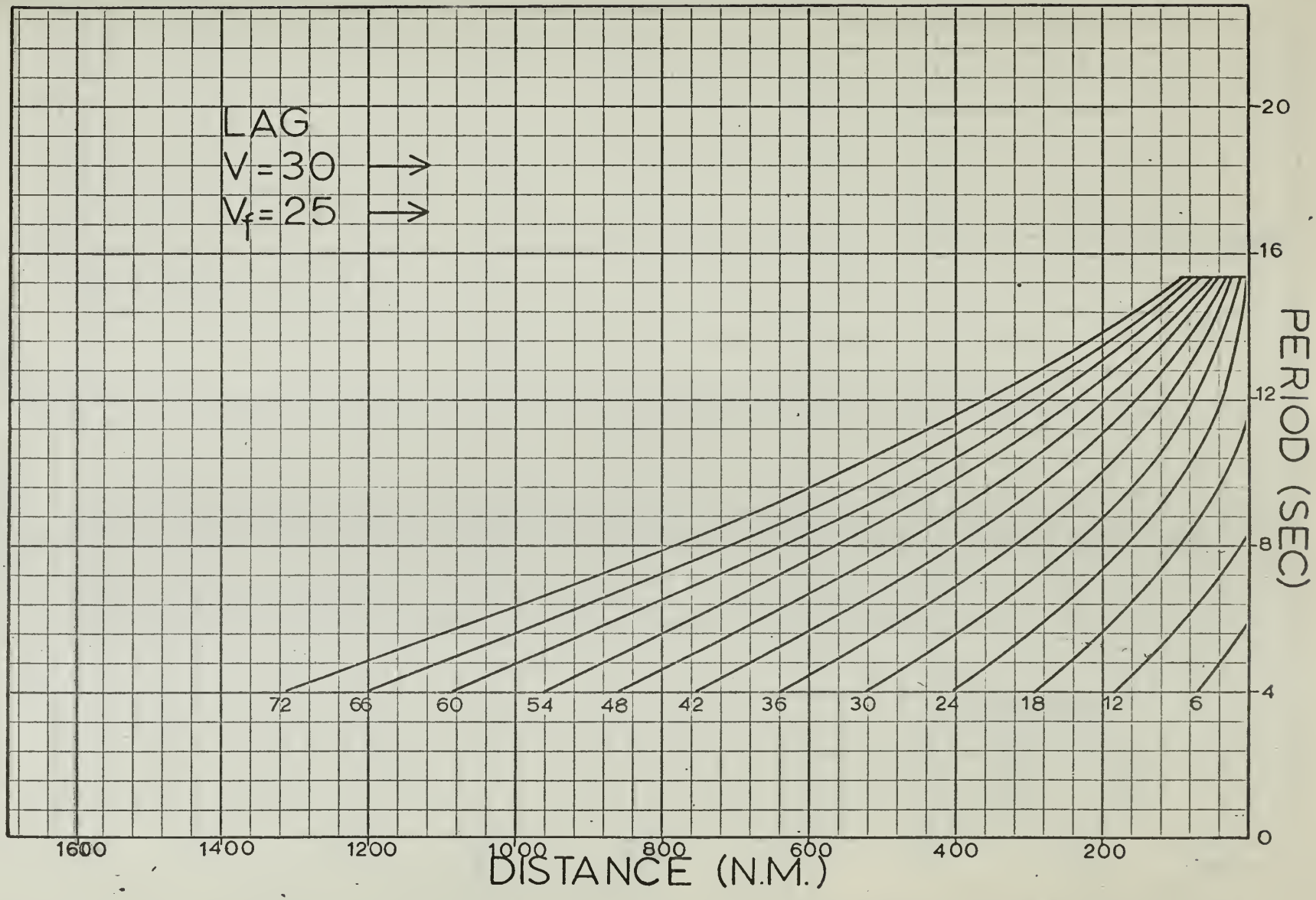


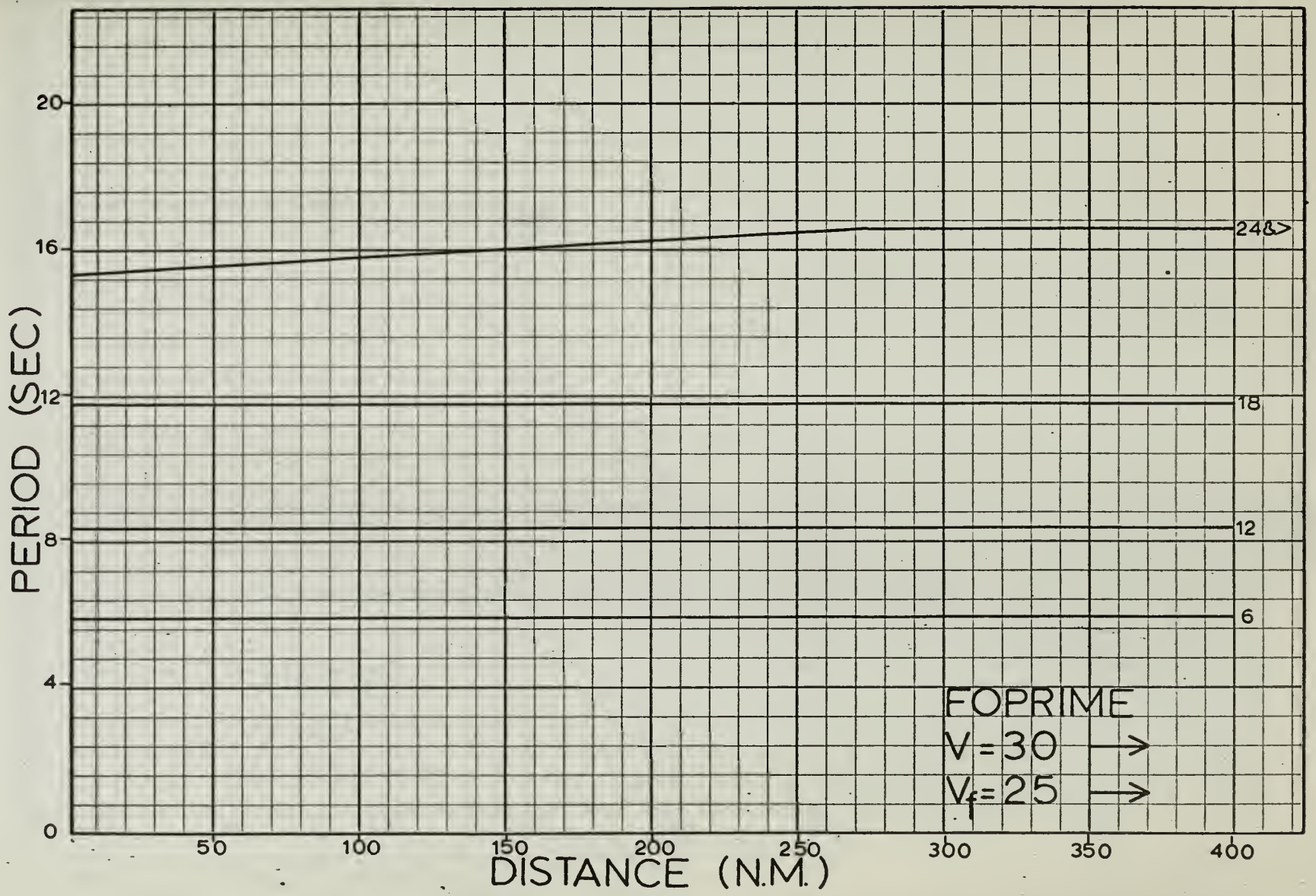

PERIOD (SEC)
0
4
8
12
16
20
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
24&>
18
12
6
FOPRIME
V = 30 →
Vf = 20 →


24&>
18
12
6
30
42
54
72
20
16
12
8
4
0
PERIOD (SEC)
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
SUMDEL
V = 30
Vf = 20

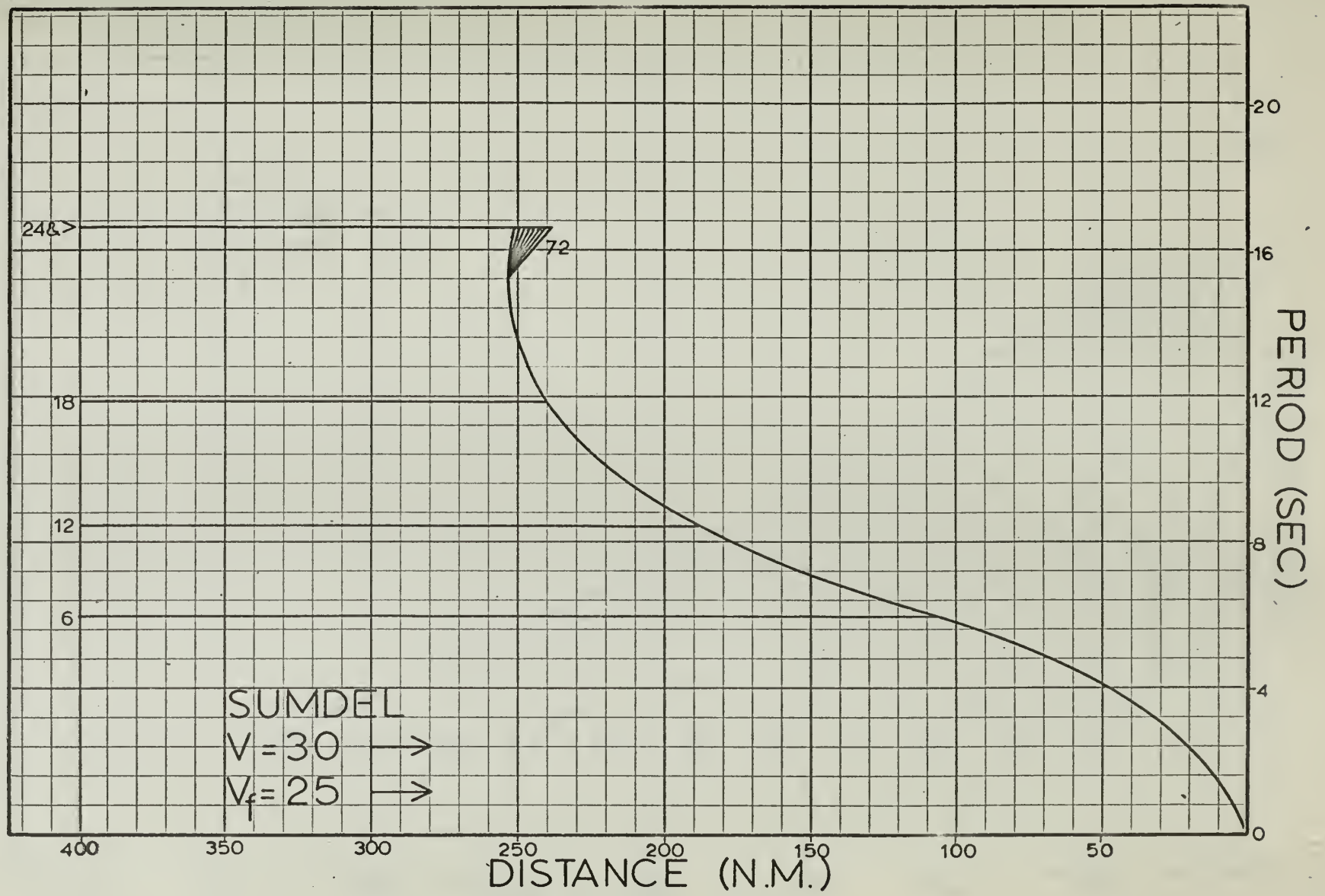

20
16
12
8
4
0
PERIOD (SEC)
54
60
66
72
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V=30 →
Vf=20 →

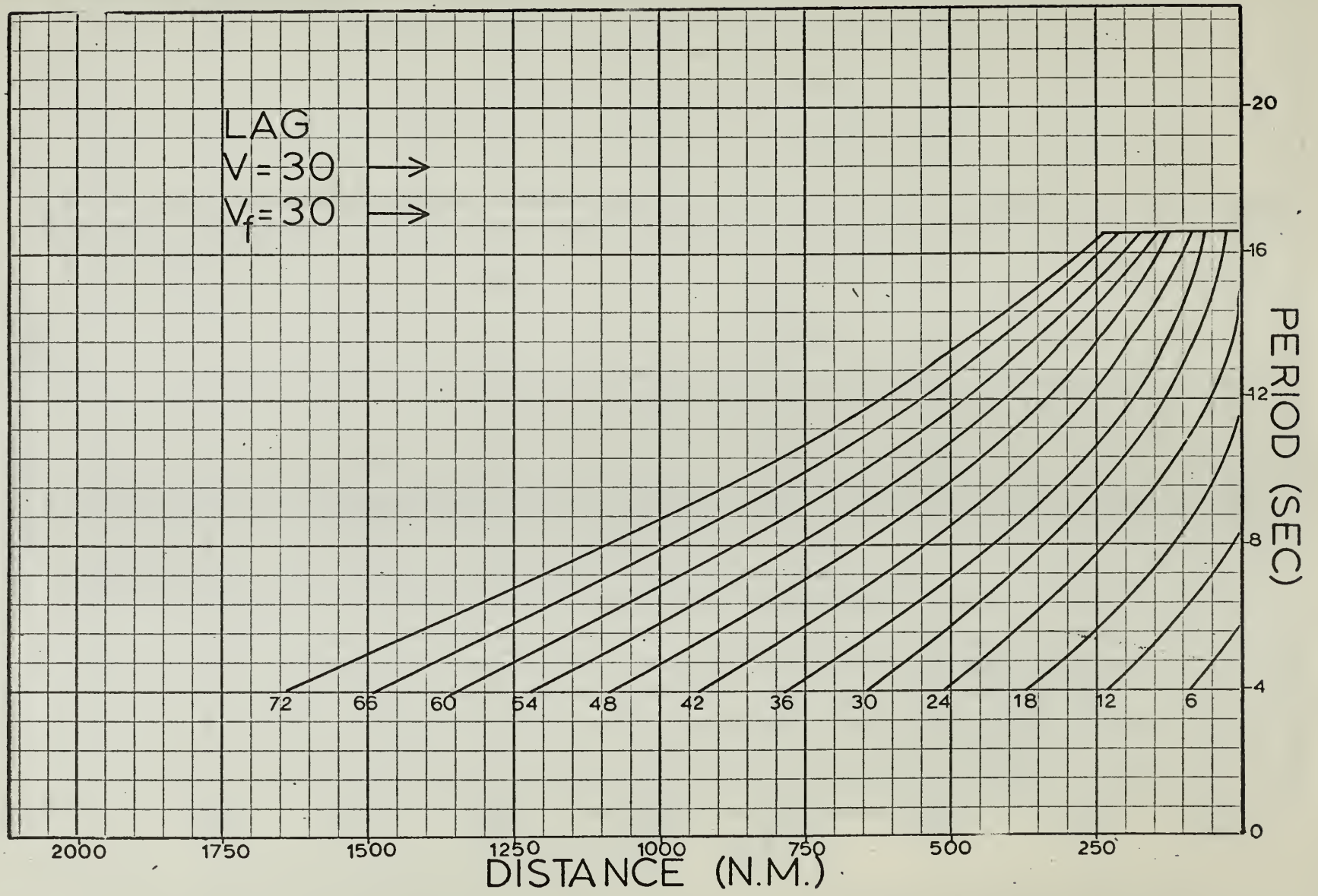



LAG
V=30
Vf=25
72
66
60
54
48
42
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
1600
1400
1200
1000
800
600
400
200
DISTANCE (N.M.)

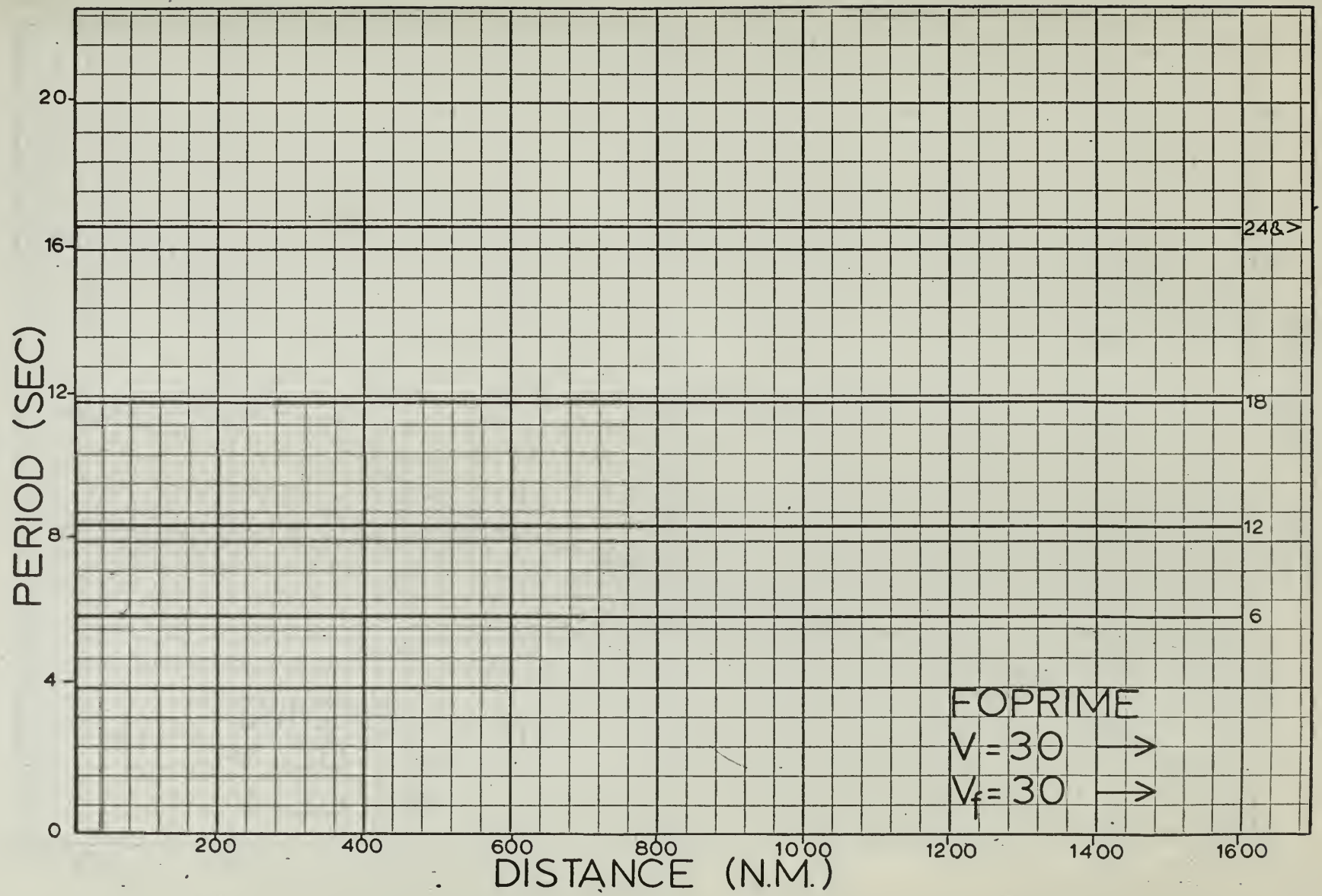

PERIOD (SEC)
0
4
8
12
16
20
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
24&>
18
12
6
FOPRIME
V = 30 →
Vf = 25 →



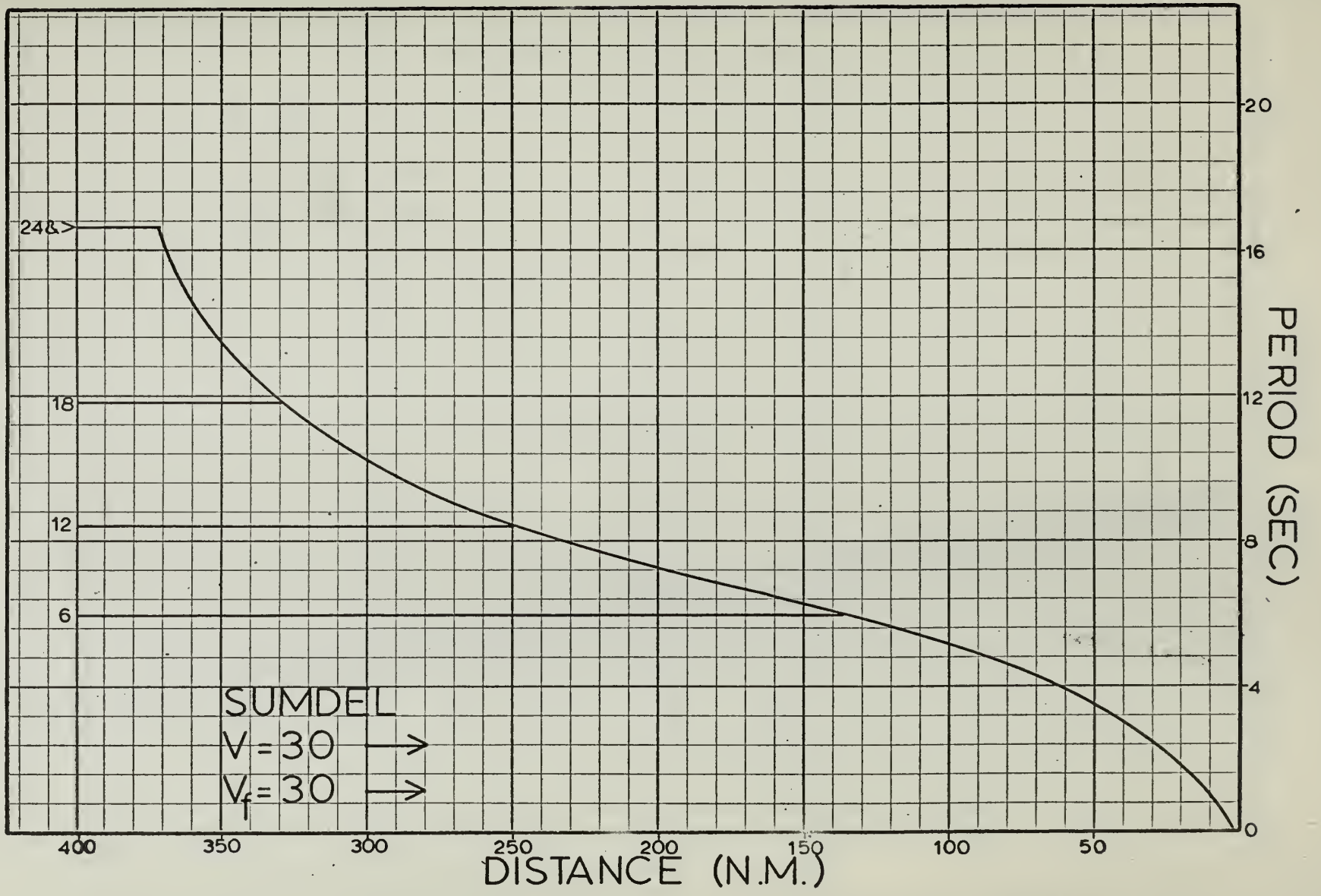

24&>
72
18
12
6
SUMDEL
V = 30 →
V_f = 25 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)


LAG
V = 30
V_f = 30
72
66
60
54
48
42
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)

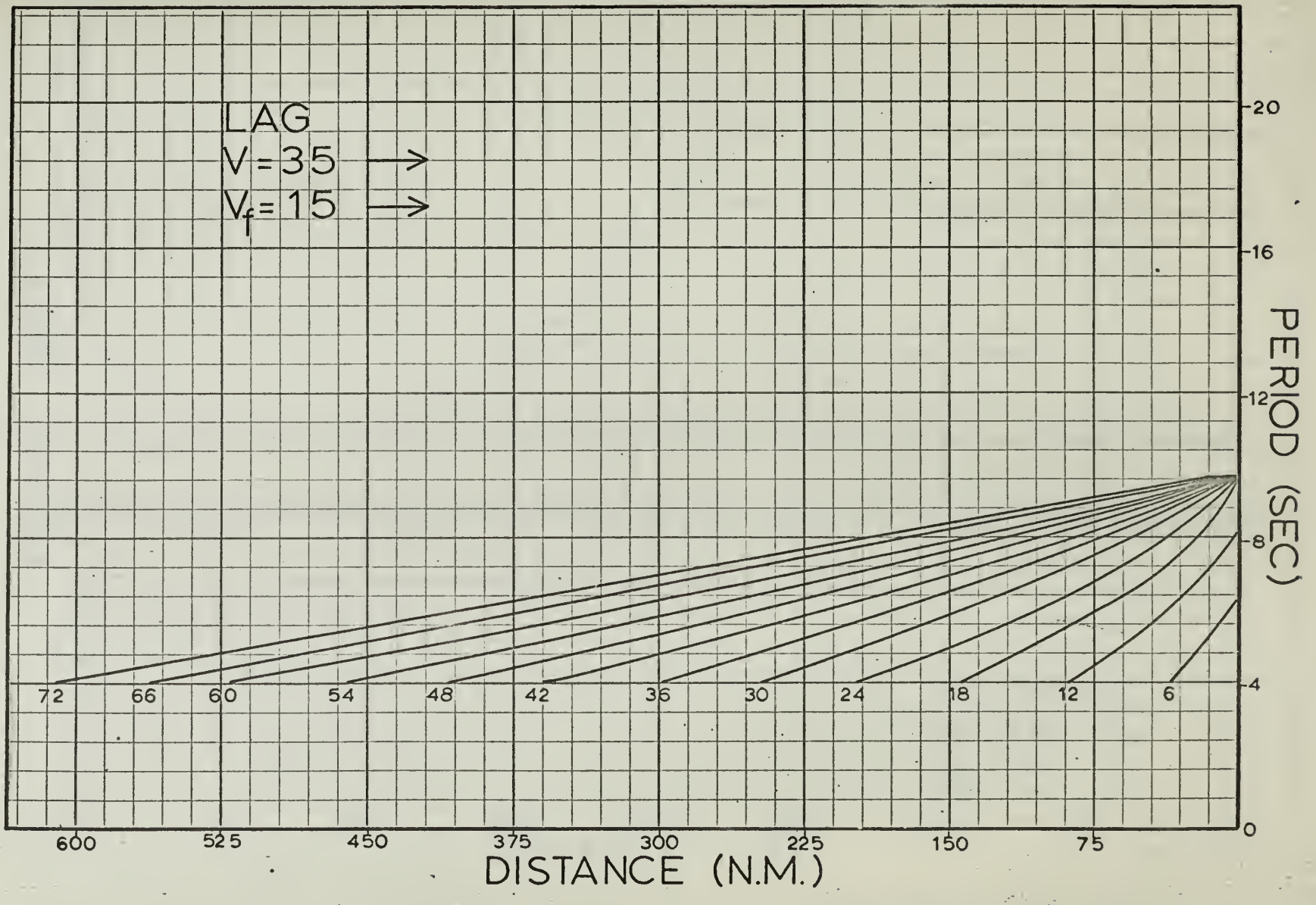



PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
24&>
18
12
6
FOPRIME
V = 30 →
Vf = 30 →

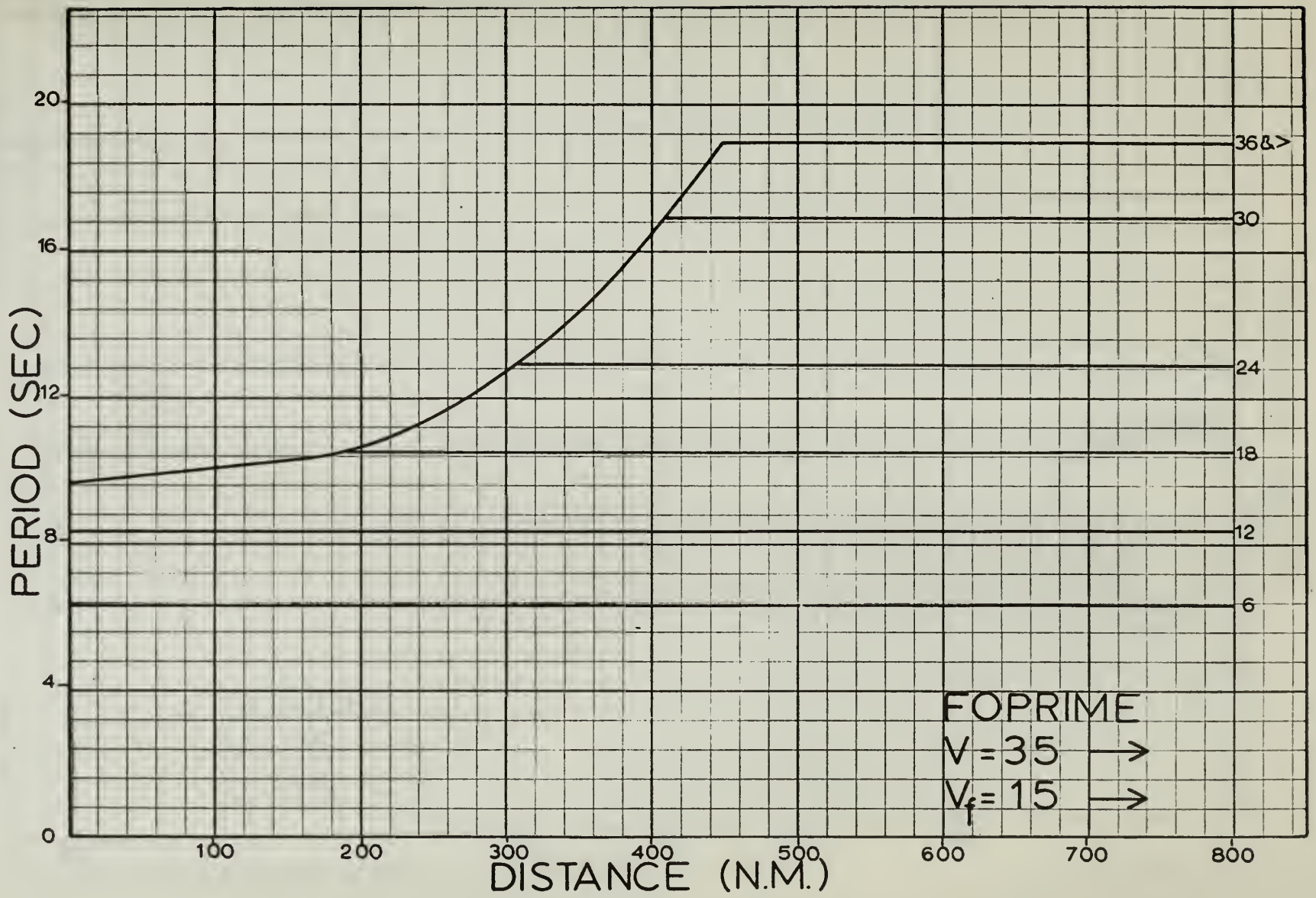



24&>
18
12
6
SUMDEL
V = 30 →
Vf = 30 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)

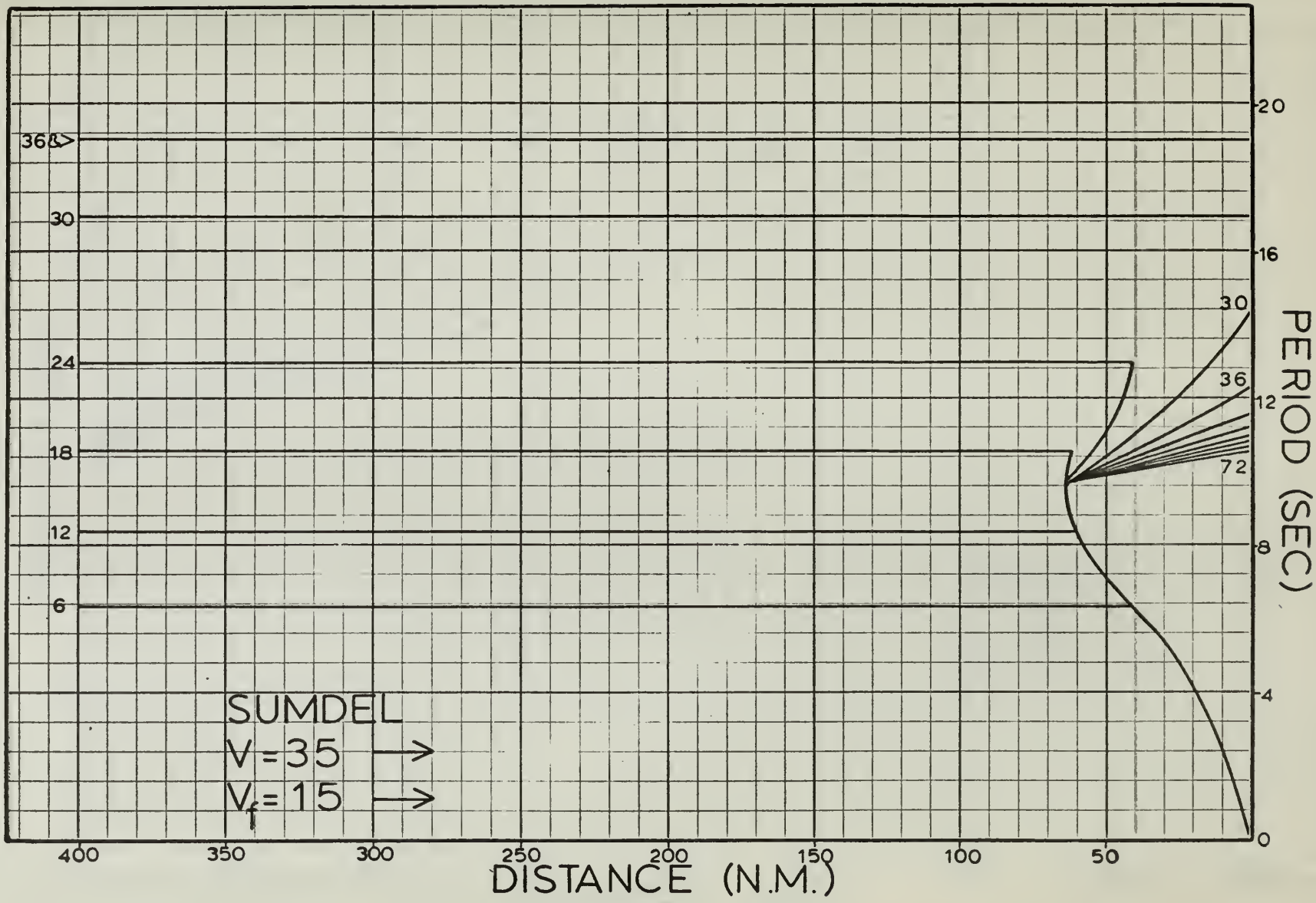



LAG
V = 35 →
V_f = 15 →
72
66
60
54
48
42
36
30
24
18
12
6
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC.)

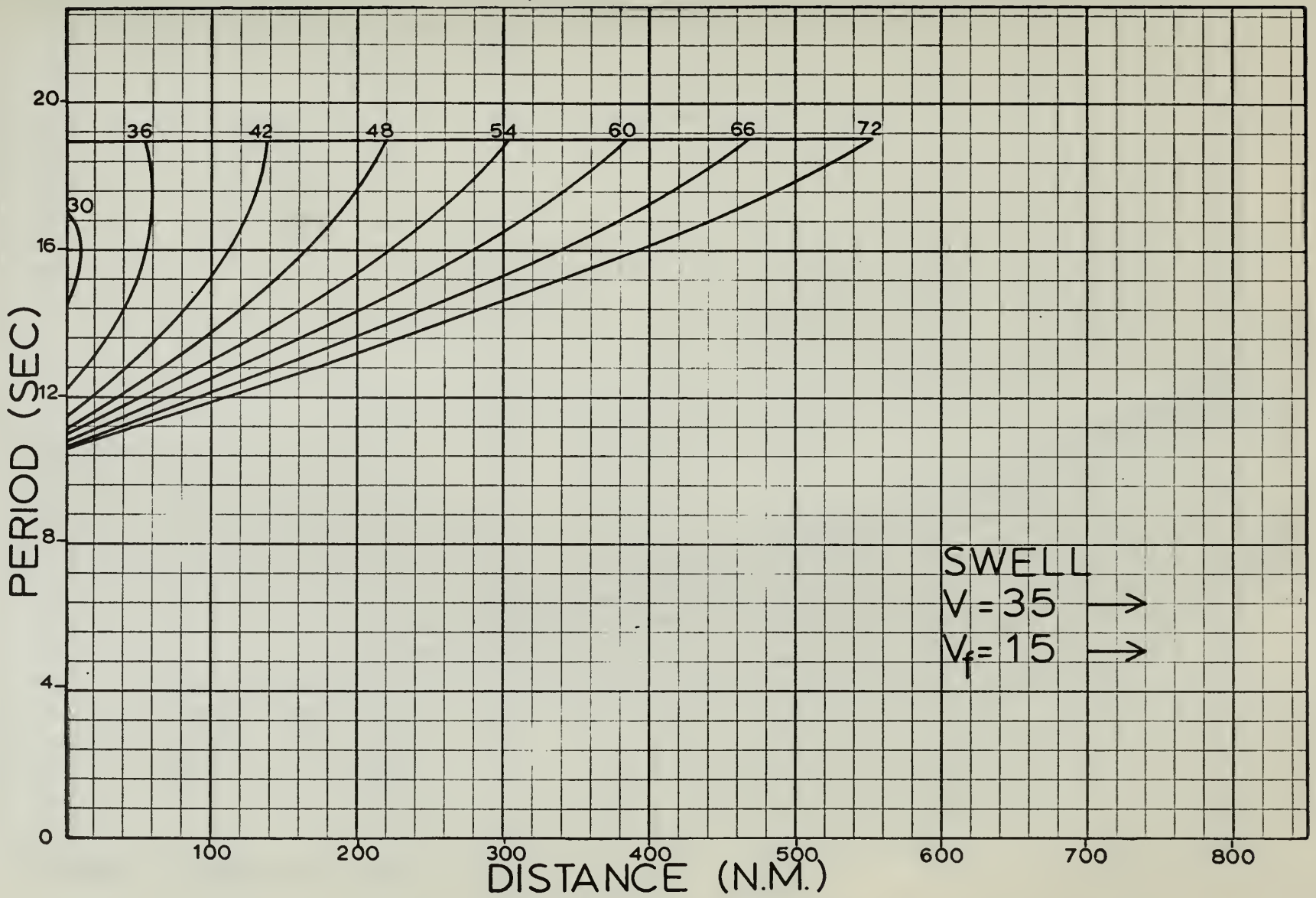



PERIOD (SEC)
0
4
8
12
16
20
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
36&>
30
24
18
12
6
FOPRIME
V = 35 →
Vf = 15 →

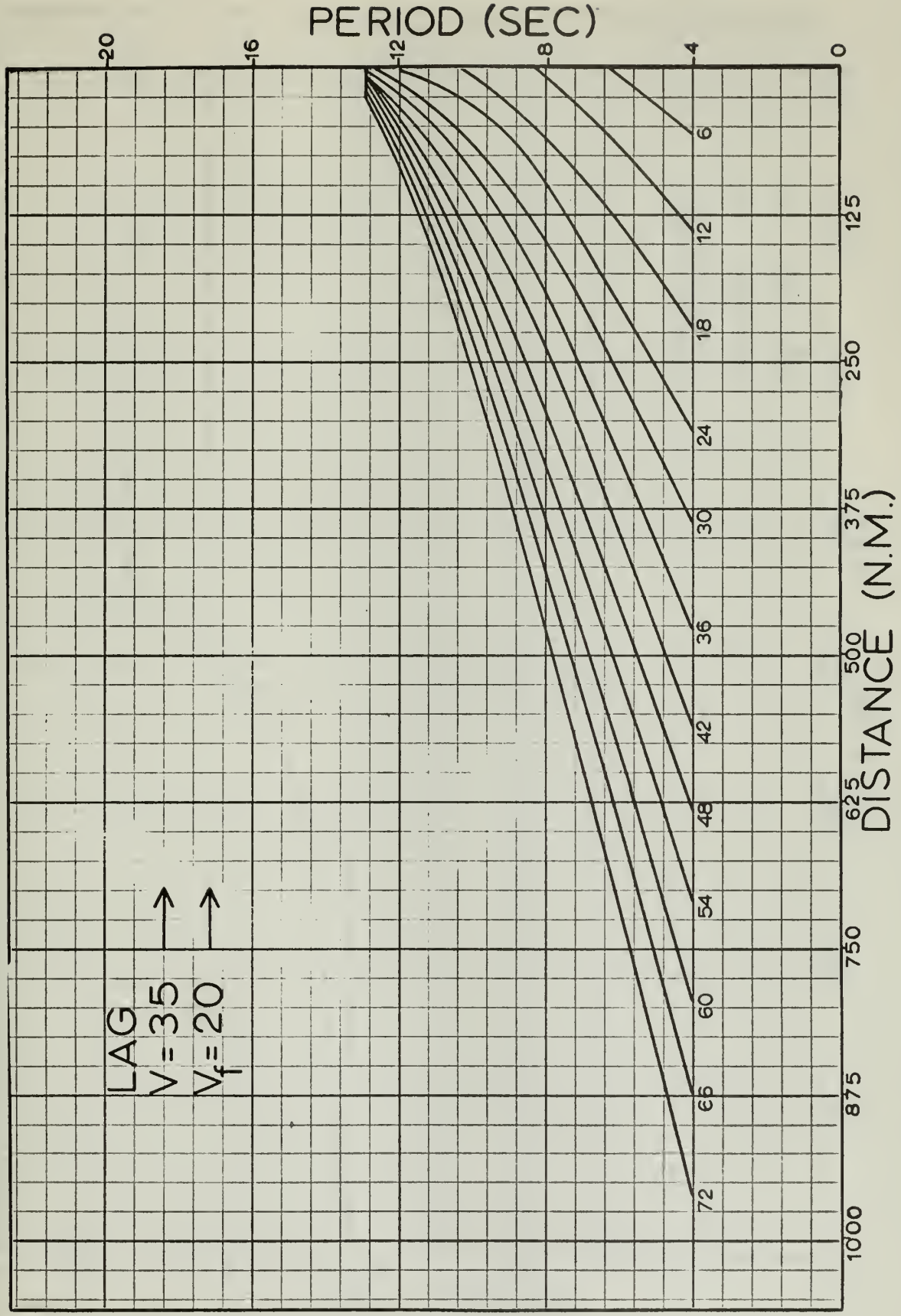



360
30
24
18
12
6
20
16
12
8
4
0
30
36
72
PERIOD (SEC)
SUMDEL
V = 35 →
V_f = 15 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)

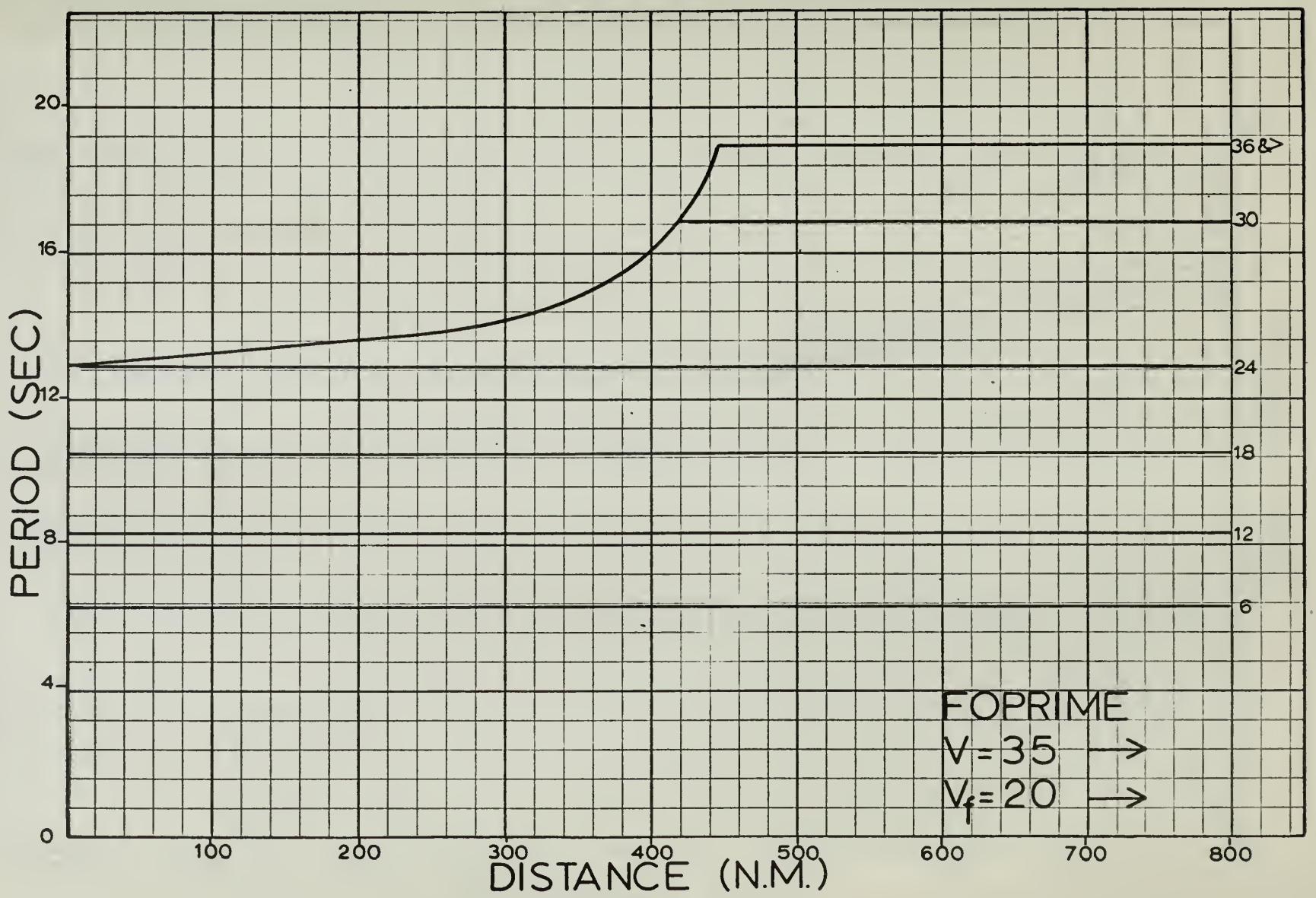



PERIOD (SEC)
0
4
8
12
16
20
30
36
42
48
54
60
66
72
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
SWELL
V = 35
V_f = 15

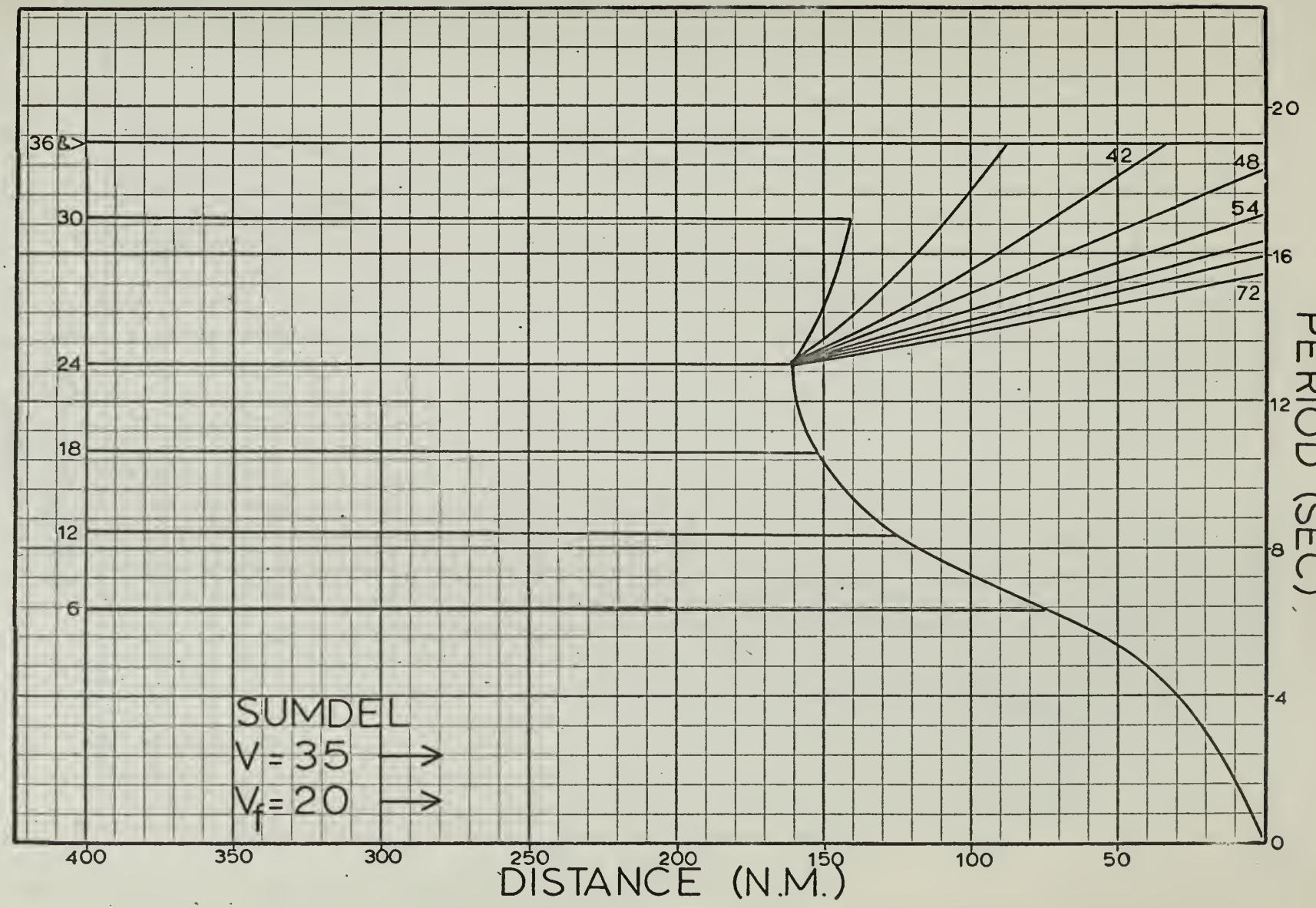



PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
125
250
375
500
625
750
875
1000
DISTANCE (N.M.)
LAG
V = 35
Vf = 20

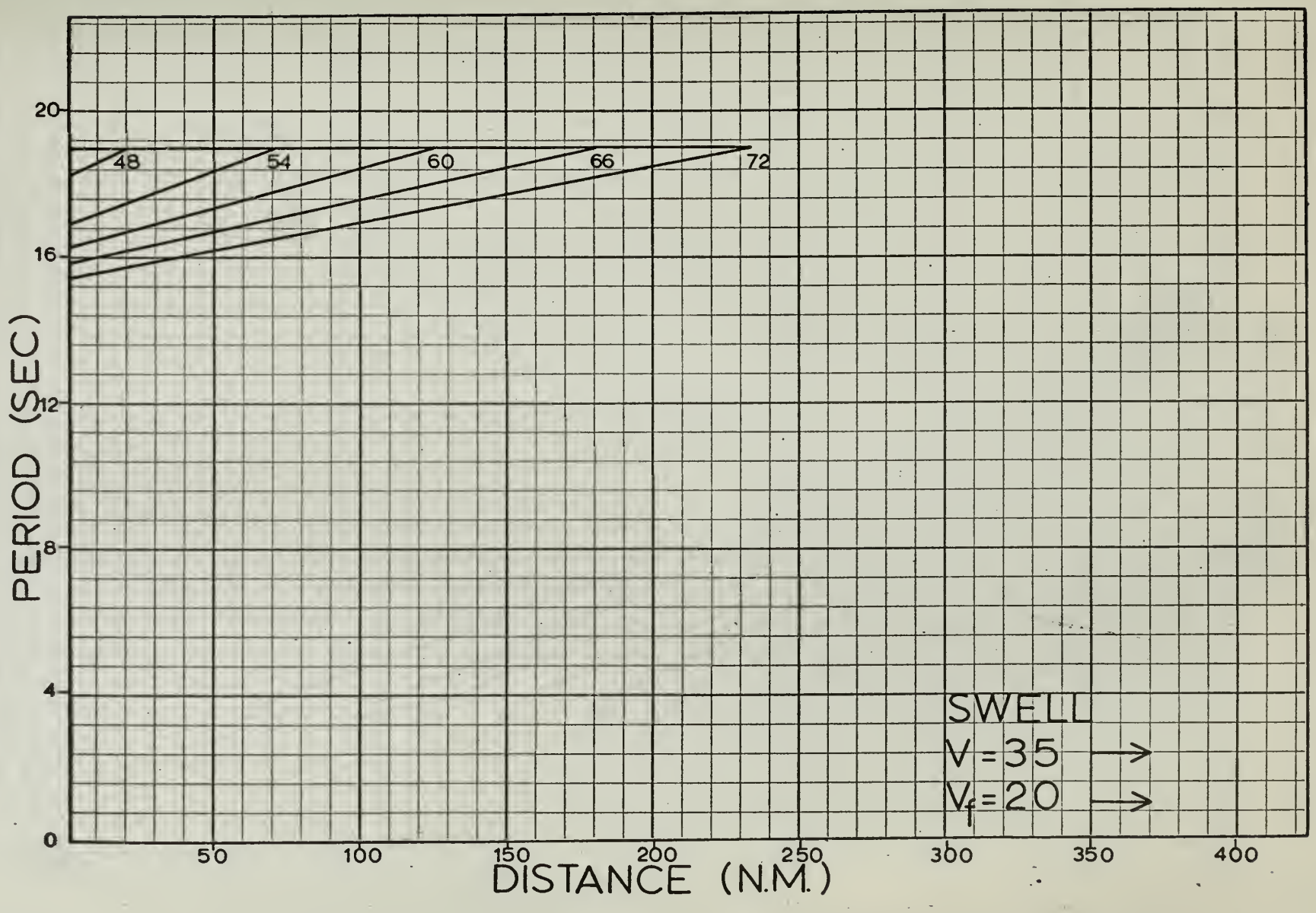



PERIOD (SEC)
0
4
8
12
16
20
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
36 &>
30
24
18
12
6
FOPRIME
V = 35 →
V_f = 20 →

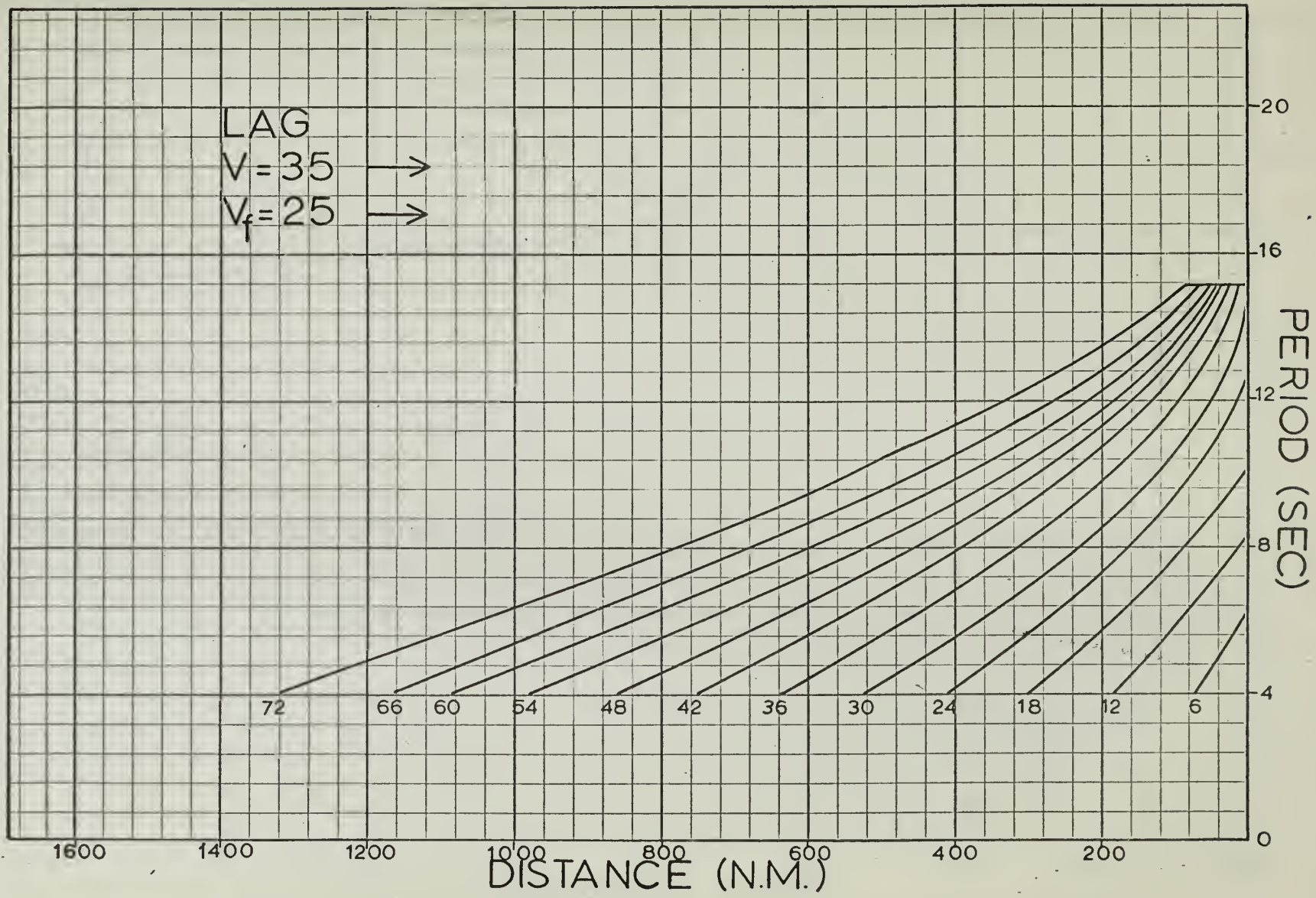


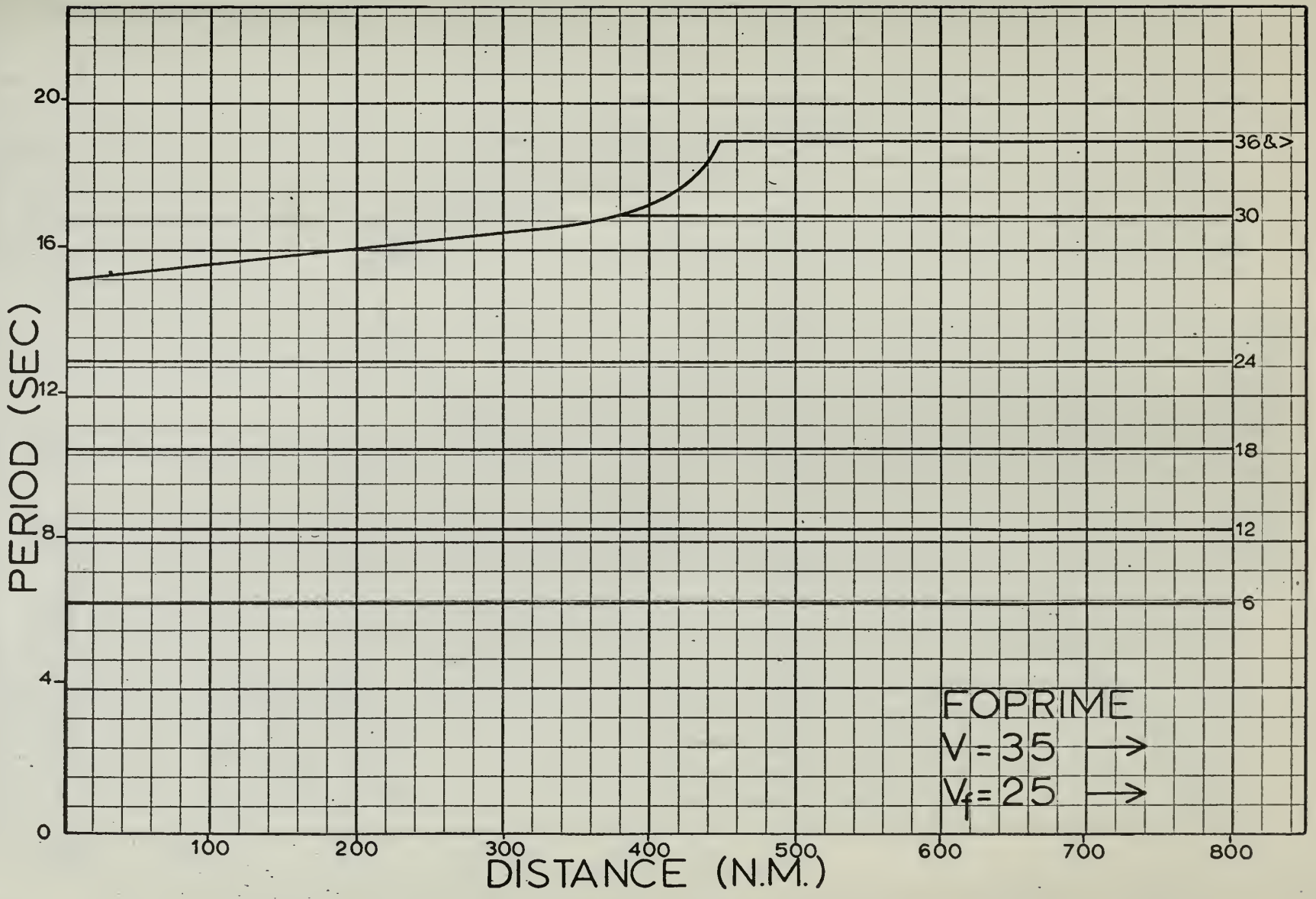

36 &>
30
24
18
12
6
42
48
54
72
20
16
12
8
4
0
PERIOD (SEC)
SUMDEL
V = 35 →
Vf = 20 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)



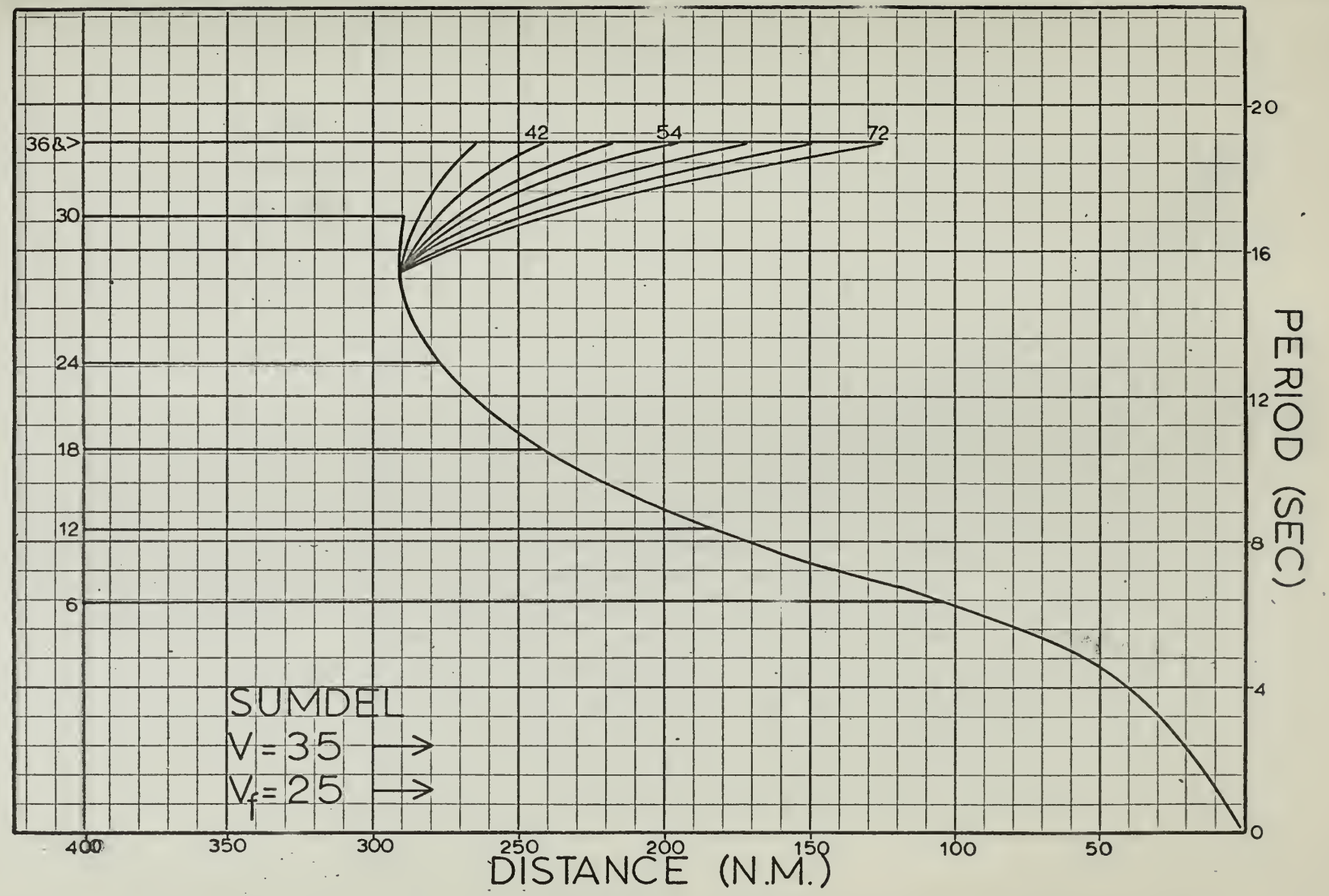

PERIOD (SEC)
0
4
8
12
16
20
48
54
60
66
72
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 35
Vf = 20



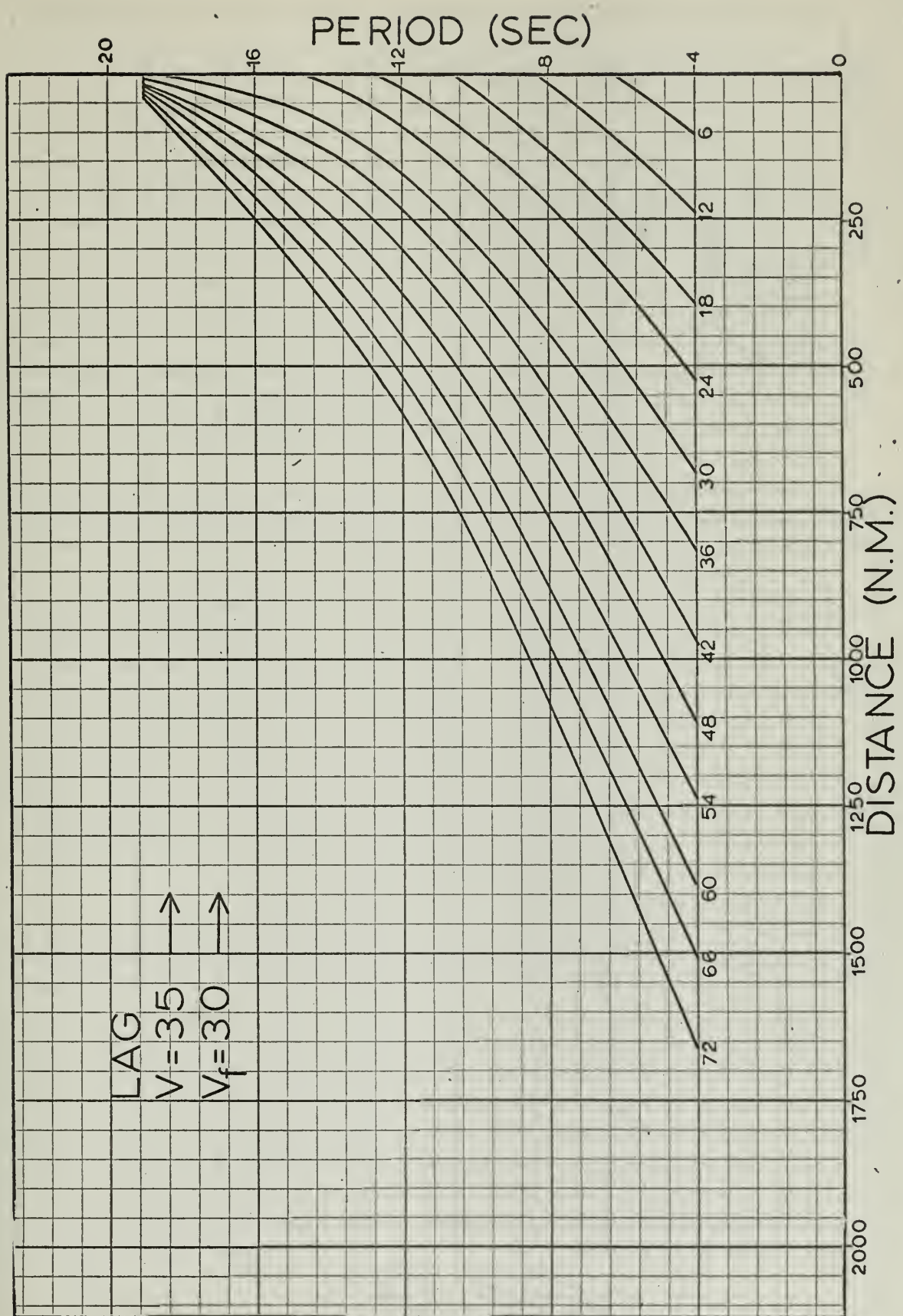

LAG
V = 35 →
Vf = 25 →
72
66
60
54
48
42
36
30
24
18
12
6
1600
1400
1200
1000
800
600
400
200
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)

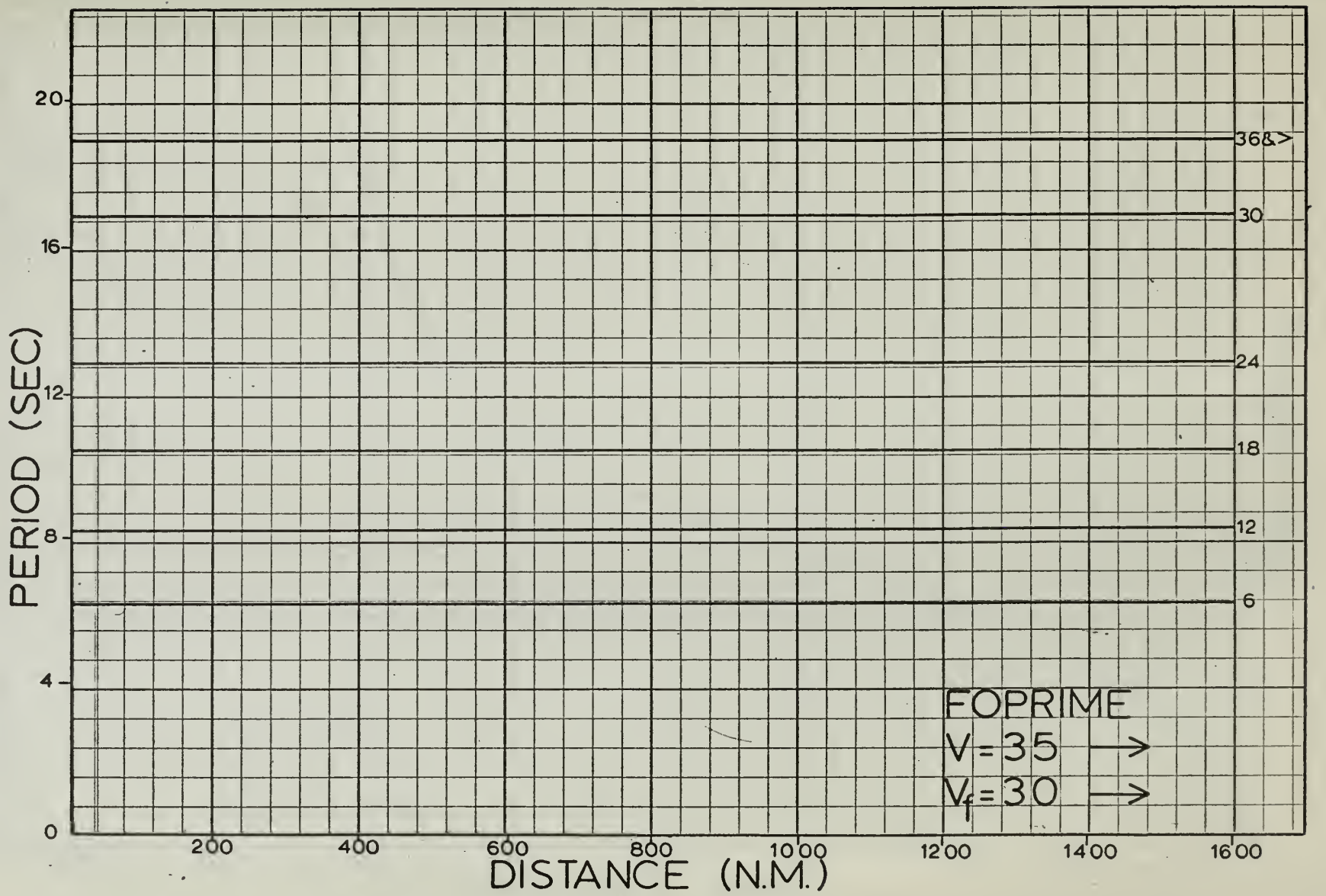

PERIOD (SEC)
0
4
8
12
16
20
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
36&>
30
24
18
12
6
FOPRIME
V = 35 →
Vf = 25 →



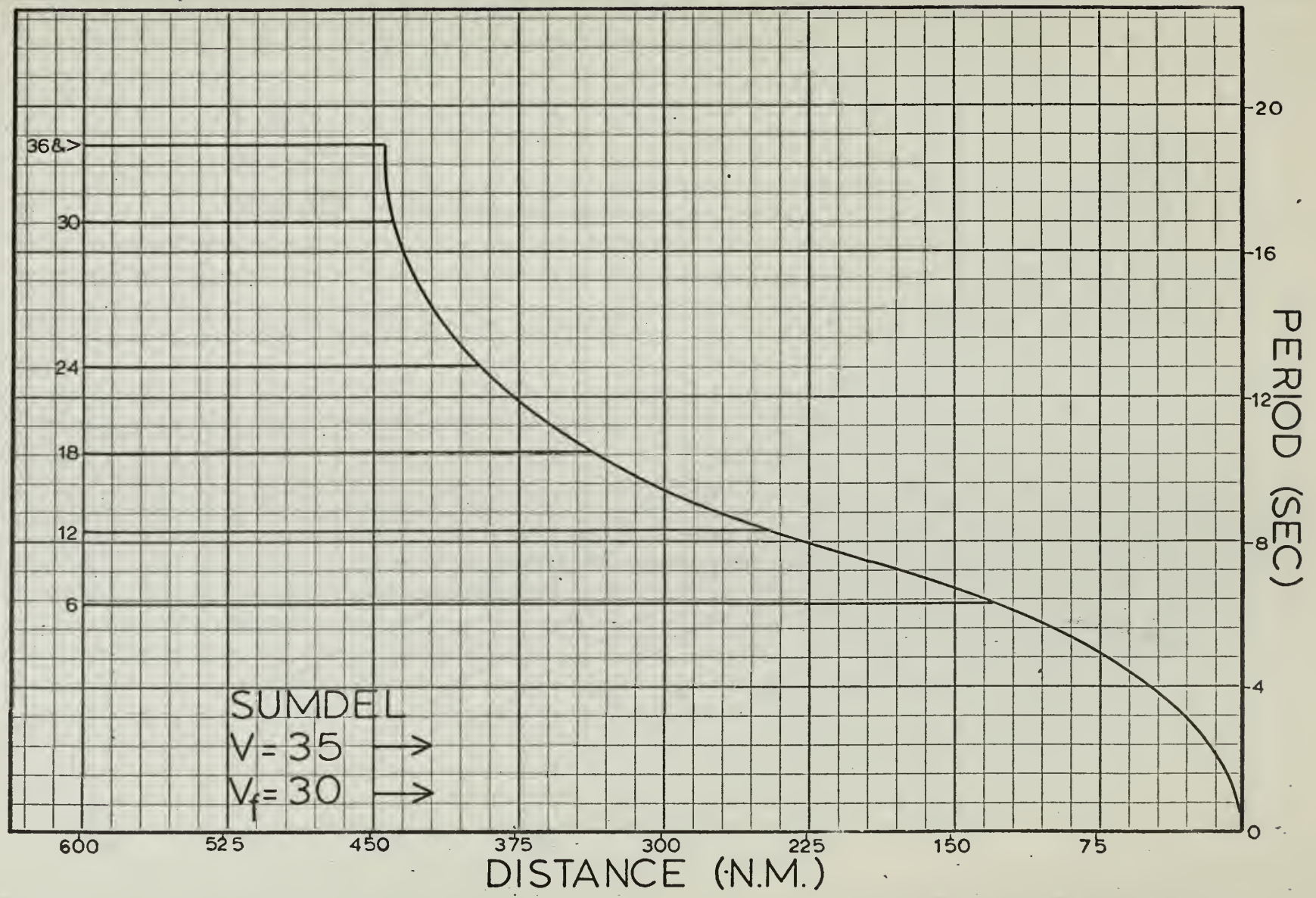

36&>
30
24
18
12
6
42
54
72
SUMDEL
V = 35 →
Vf = 25 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)



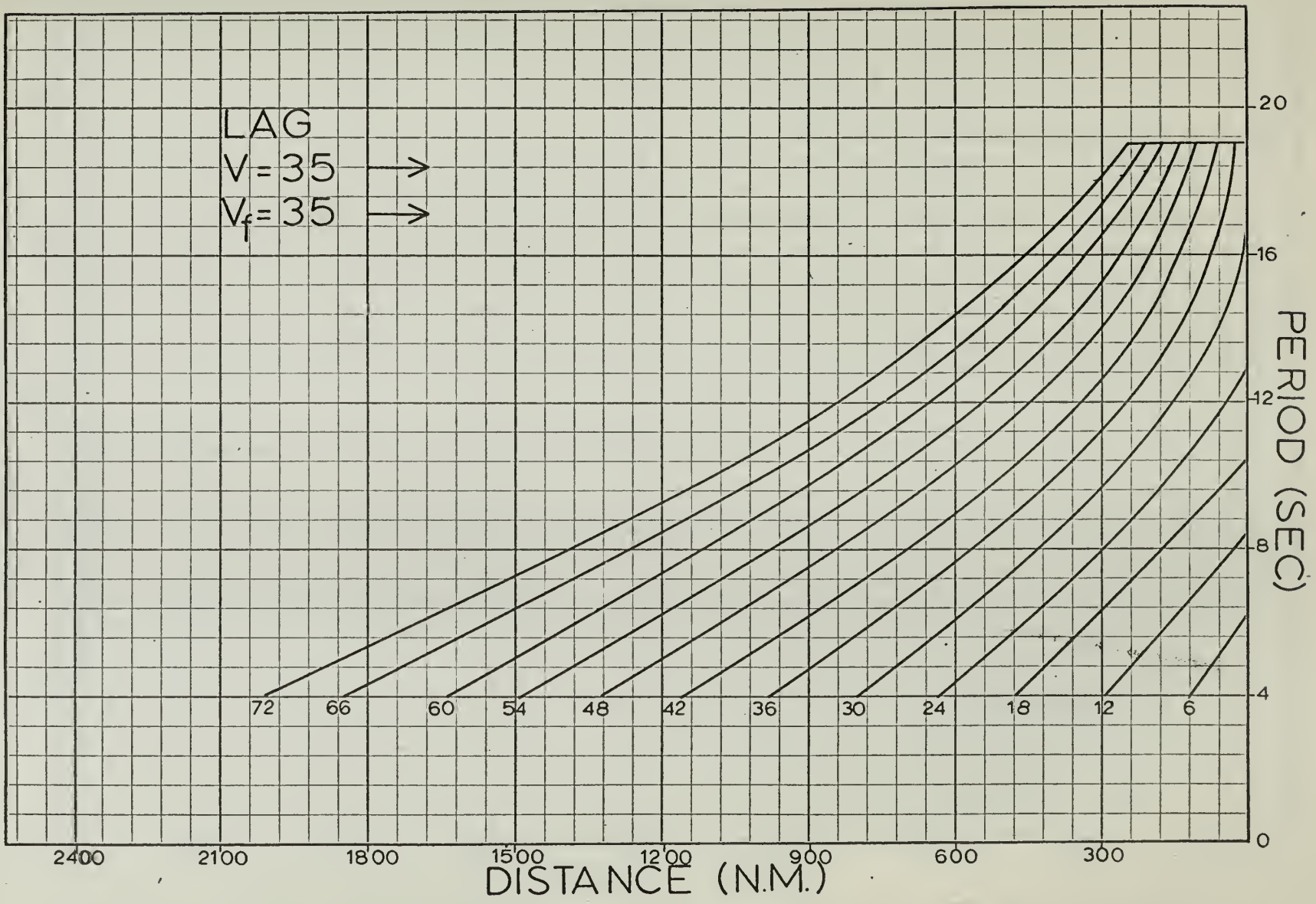

PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
LAG
V=35
Vf=30
250
500
750
1000
1250
1500
1750
2000
DISTANCE (N.M.)


PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
36&>
30
24
18
12
6
FOPRIME
V=35 →
Vf=30 →

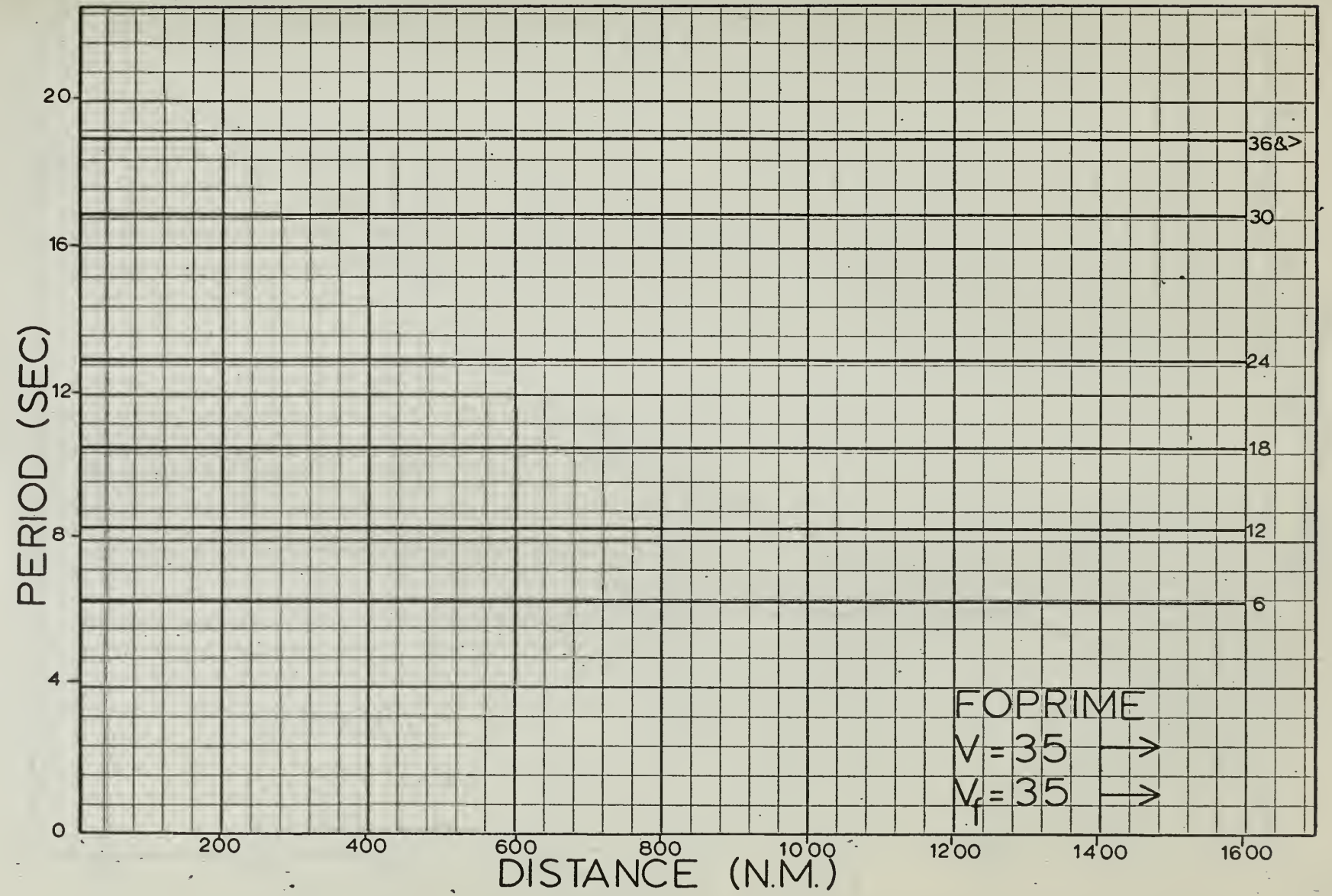



36&>
30
24
18
12
6
SUMDEL
V = 35 →
Vf = 30 →
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)

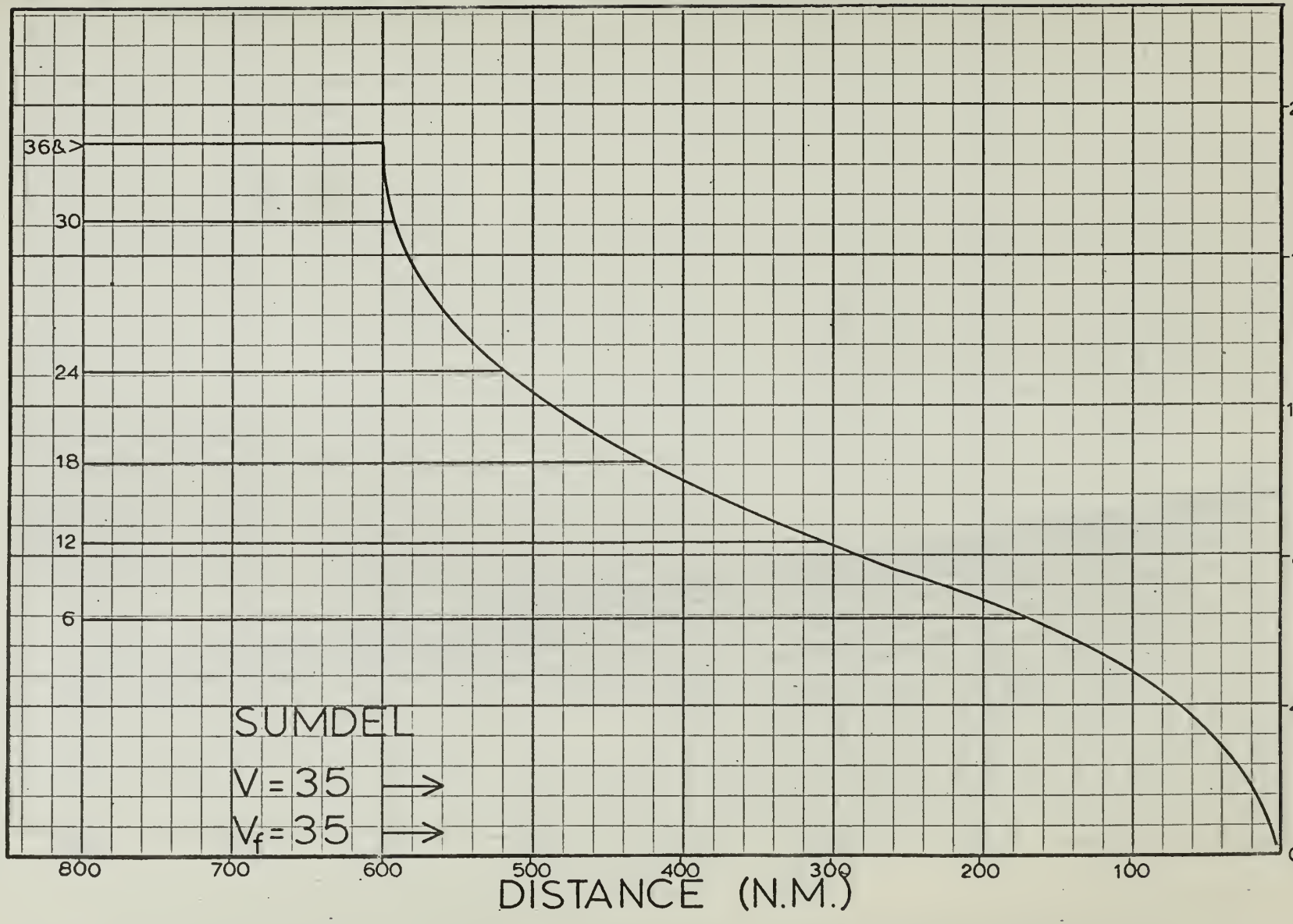



LAG
V = 35 →
V_f = 35 →
72
66
60
54
48
42
36
30
24
18
12
6
2400
2100
1800
1500
1200
900
600
300
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

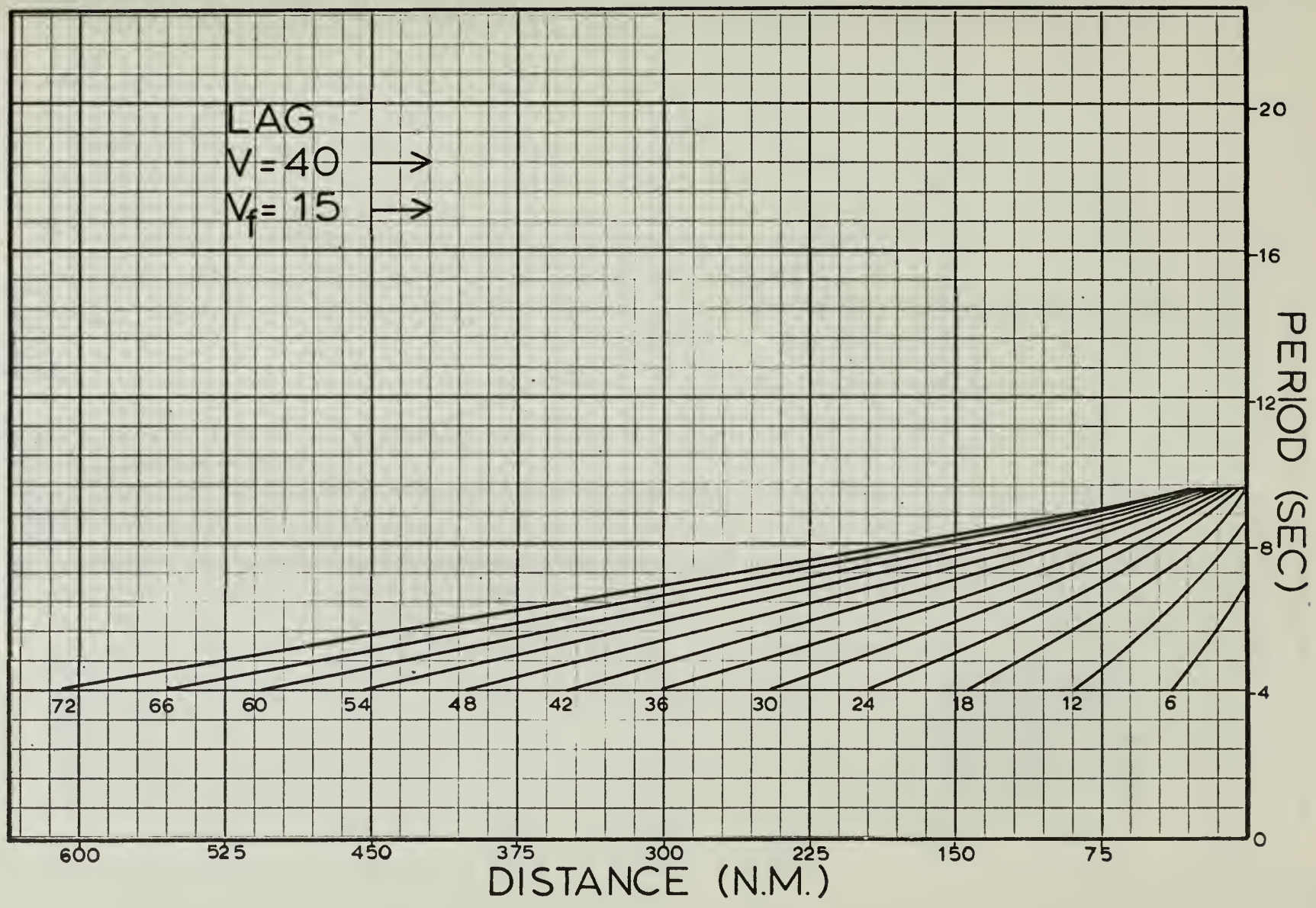



PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36&>
30
24
18
12
6
FOPRIME
V = 35
Vf = 35

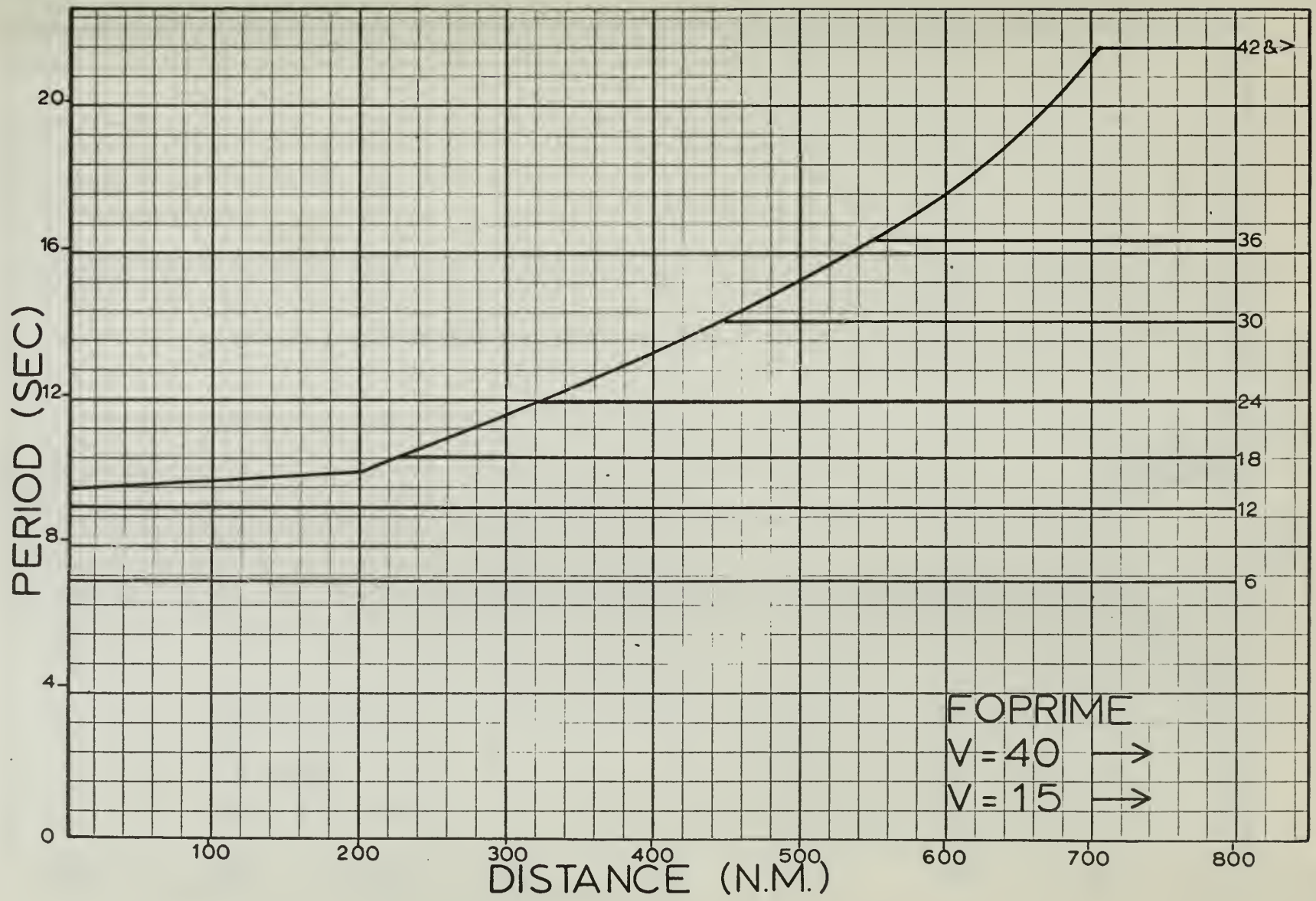



36&>
30
24
18
12
6
SUMDEL
V = 35 →
Vf = 35 →
800
700
600
500
400
300
200
100
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)

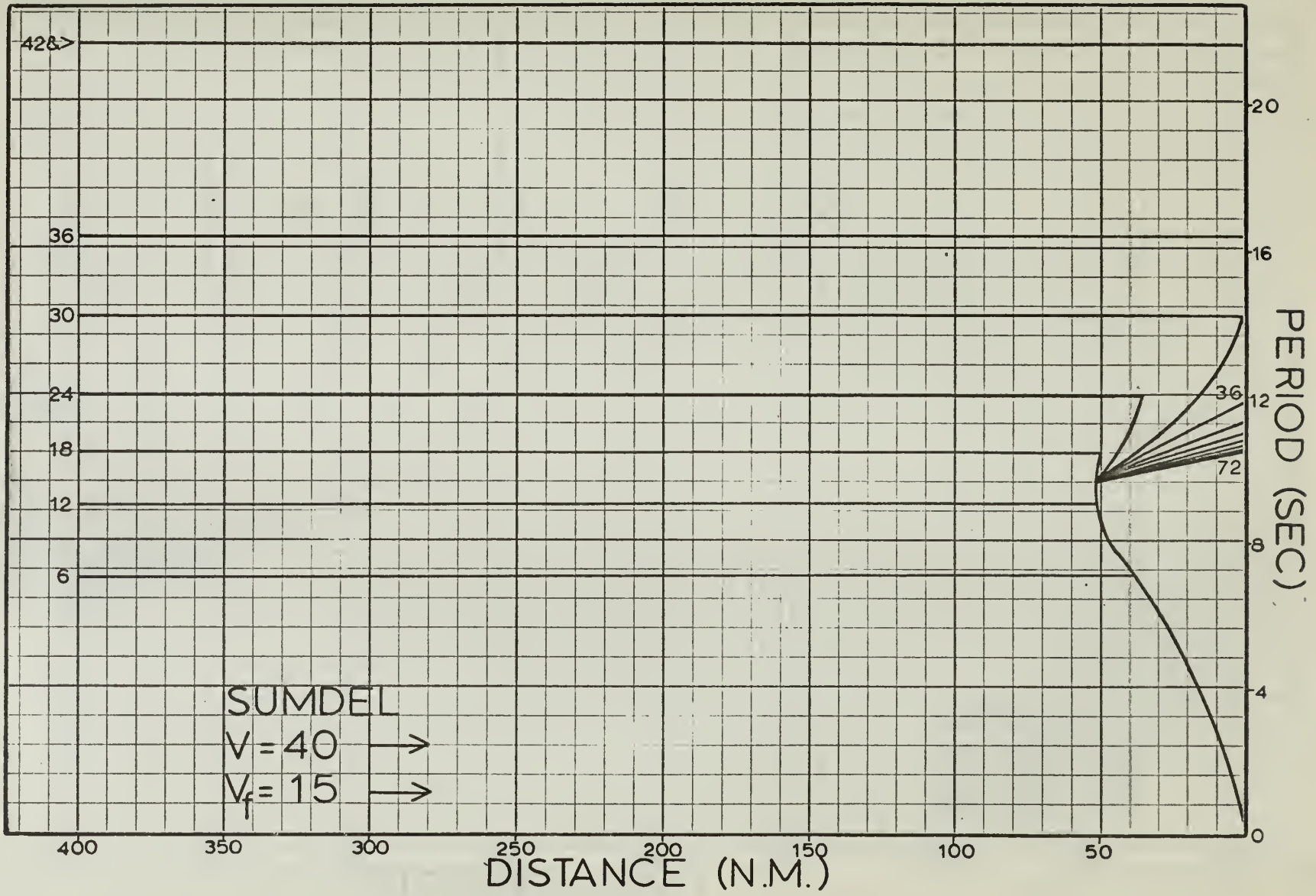



LAG
V = 40
Vf = 15
72
66
60
54
48
42
36
30
24
18
12
6
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

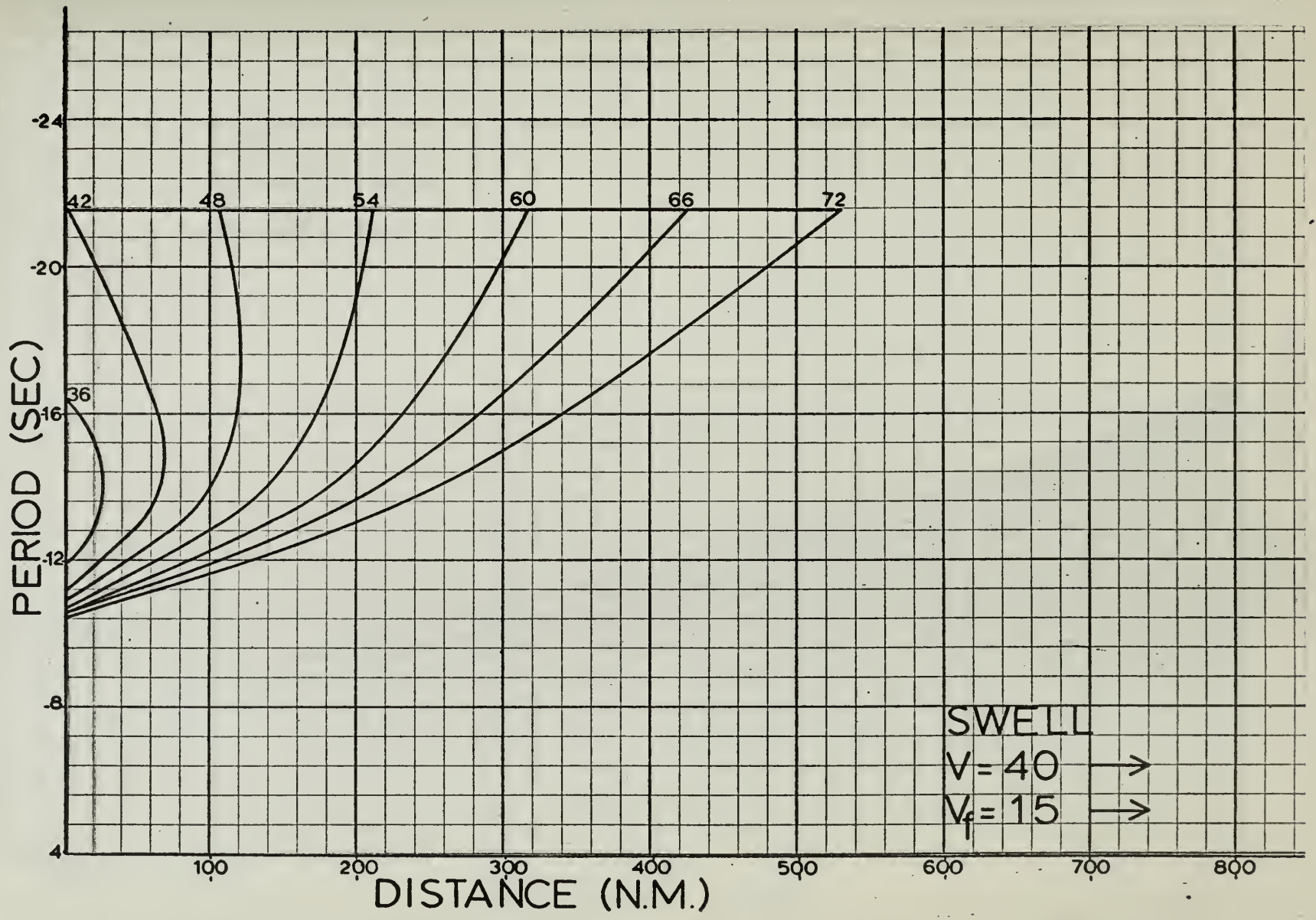



PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
42&>
36
30
24
18
12
6
FOPRIME
V=40 →
V=15 →

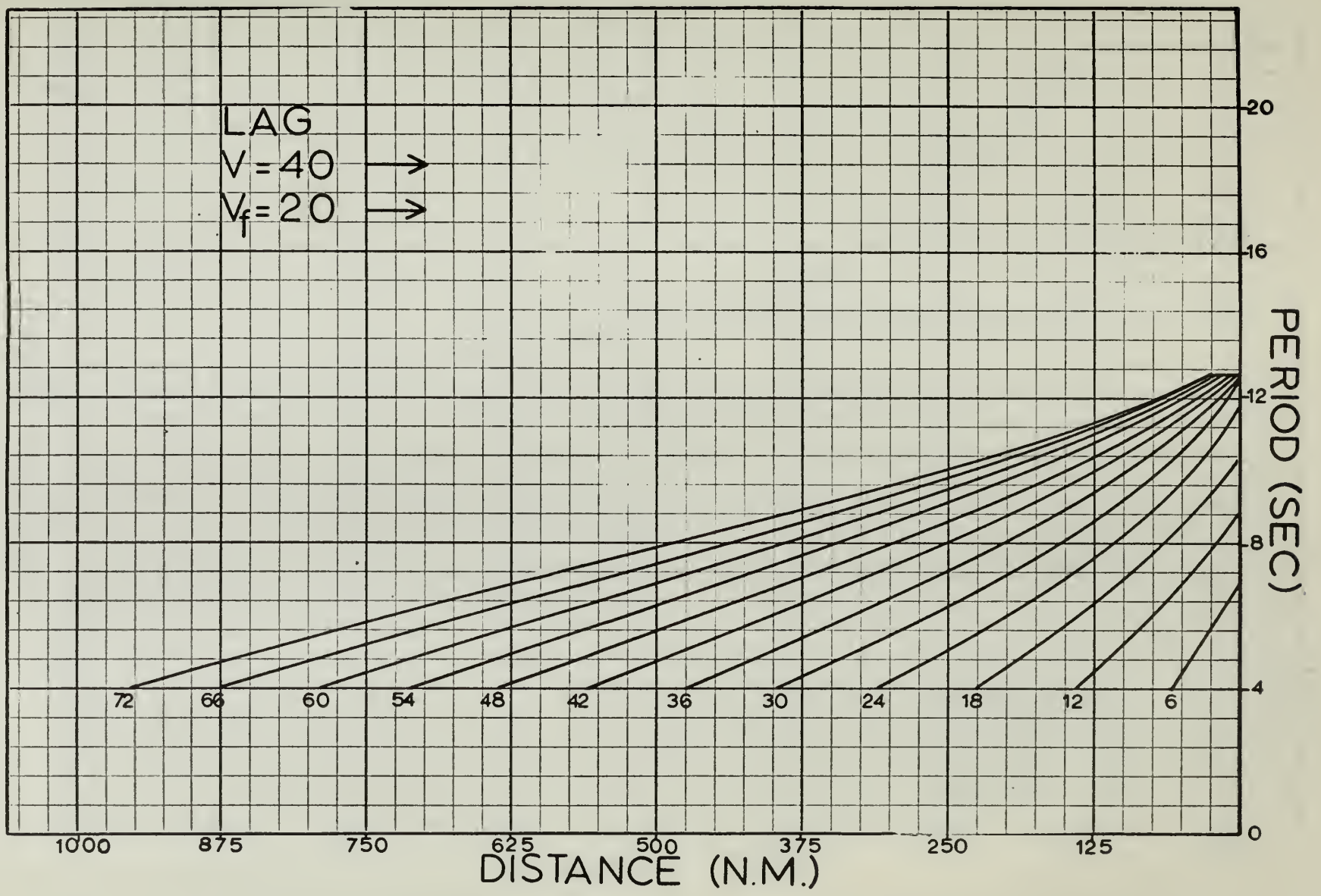



42&>
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
36
72
SUMDEL
V = 40 →
V_f = 15 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)

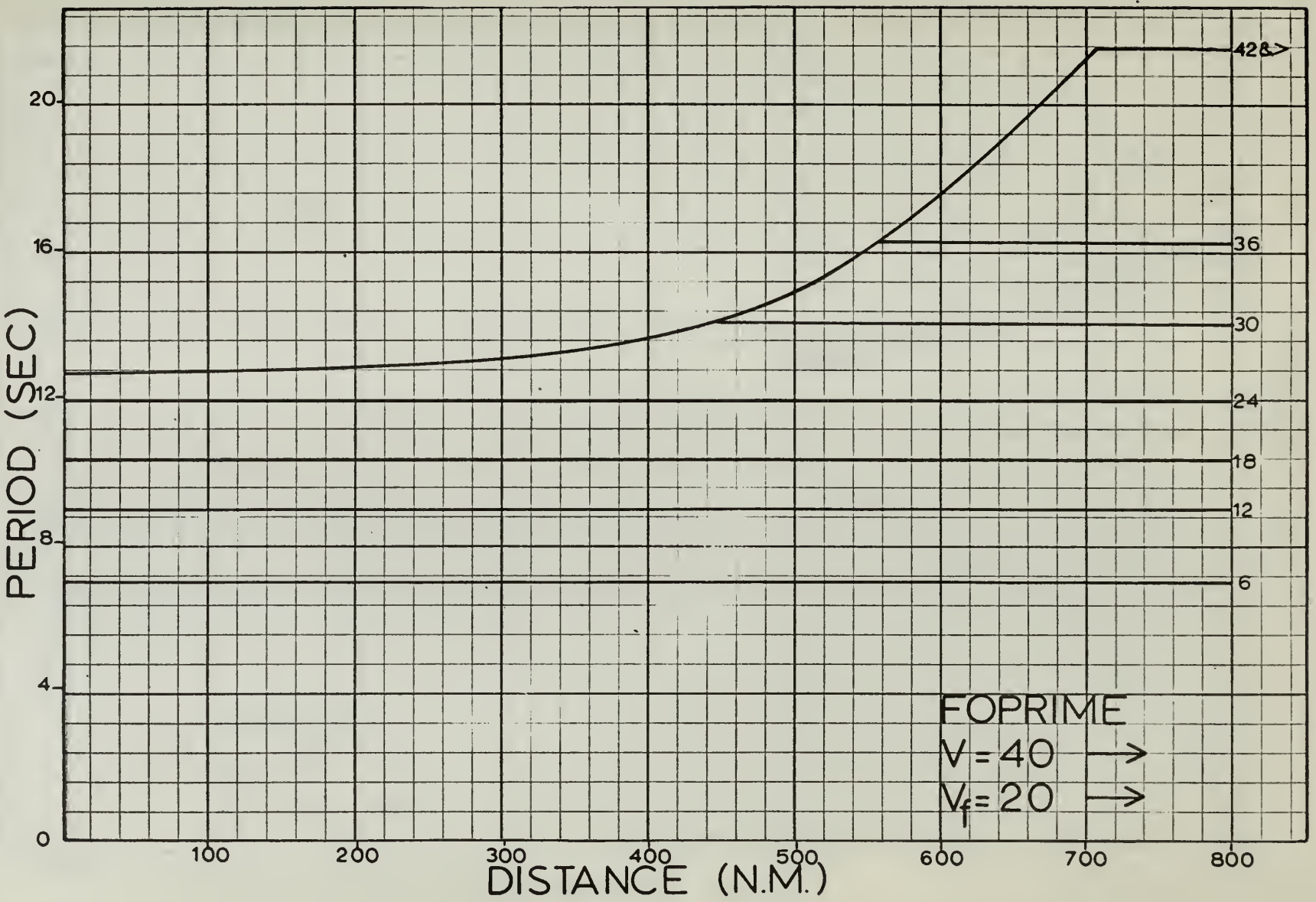



PERIOD (SEC)
24
20
16
12
8
4
42
48
54
60
66
72
36
100
200
300
400
500
600
700
800
DISTANCE (N.M.)
SWELL
V = 40 →
Vf = 15 →

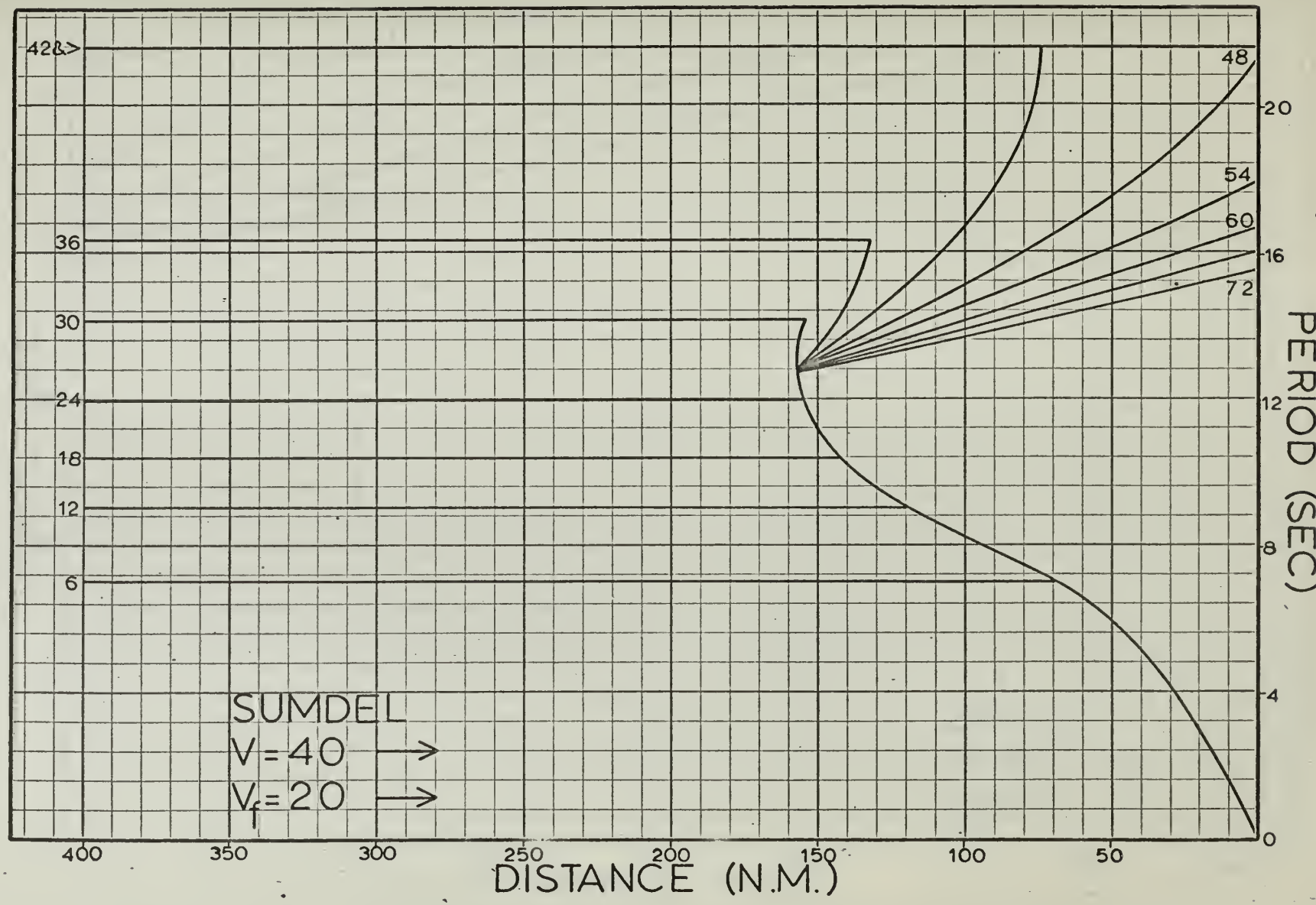



LAG
V = 40 →
Vf = 20 →
72
66
60
54
48
42
36
30
24
18
12
6
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

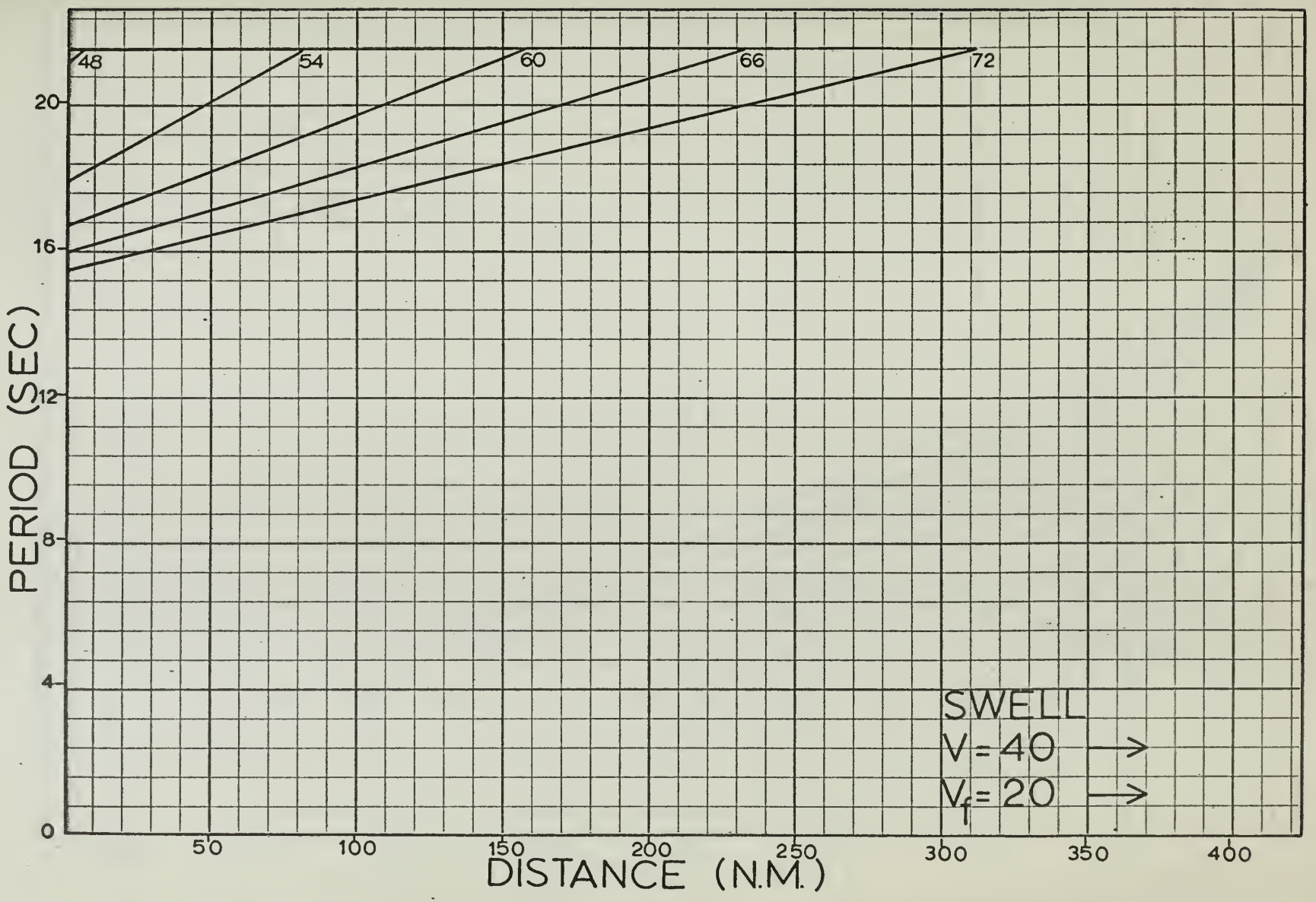


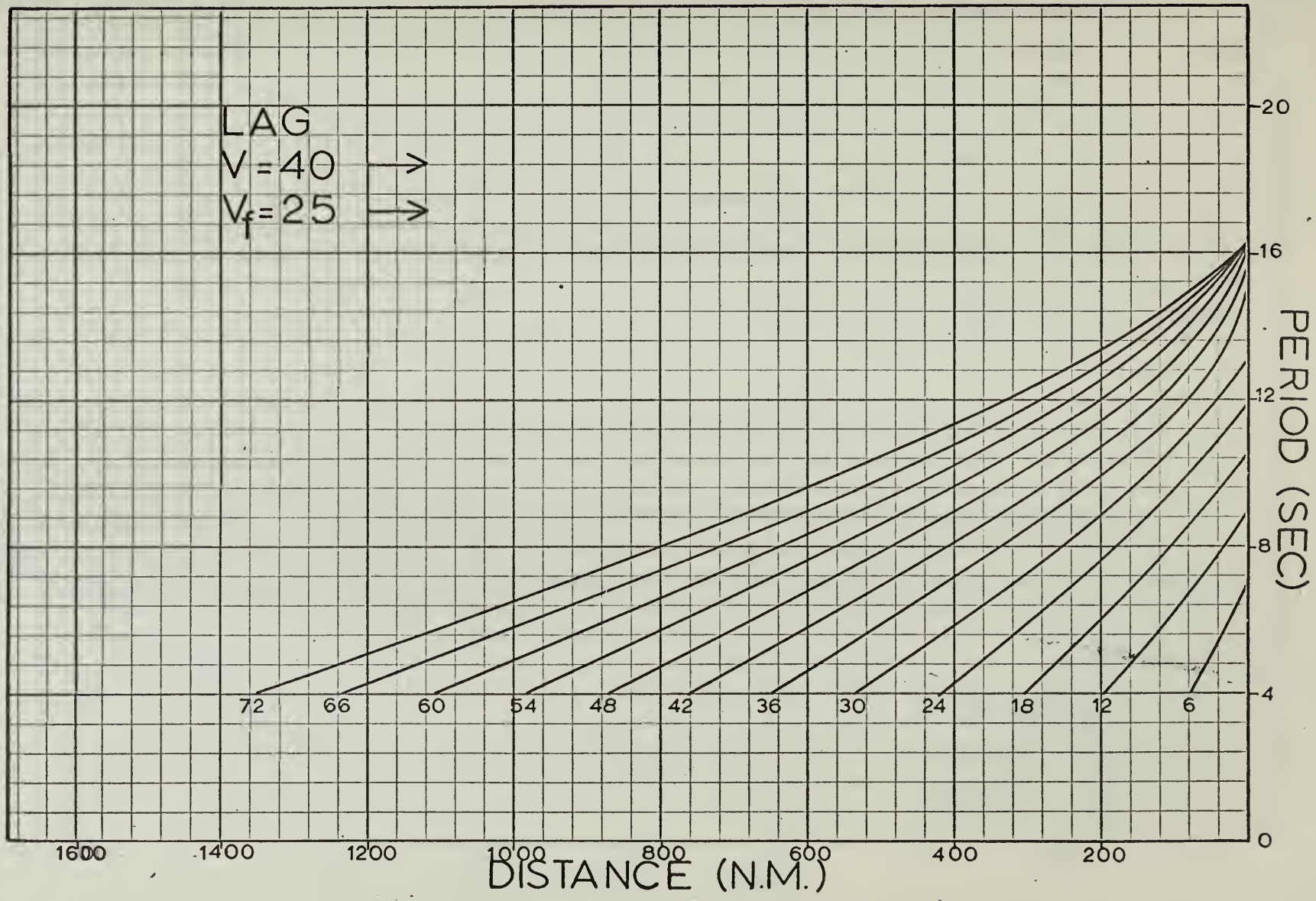

PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
42
36
30
24
18
12
6
FOPRIME
V = 40
Vf = 20

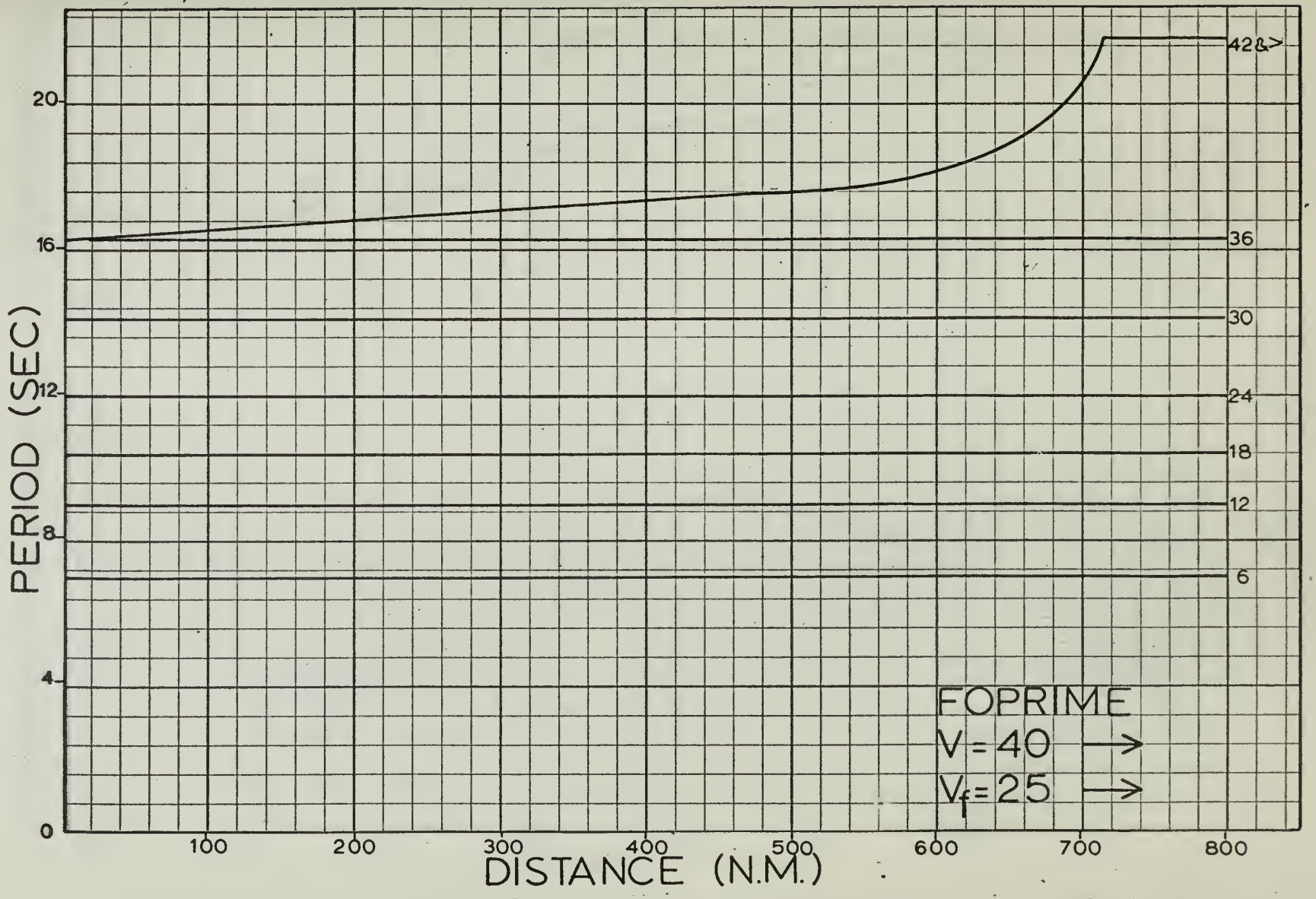



42&>
36
30
24
18
12
6
48
54
60
72
20
16
12
8
4
0
PERIOD (SEC)
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
SUMDEL
V = 40 →
Vf = 20 →

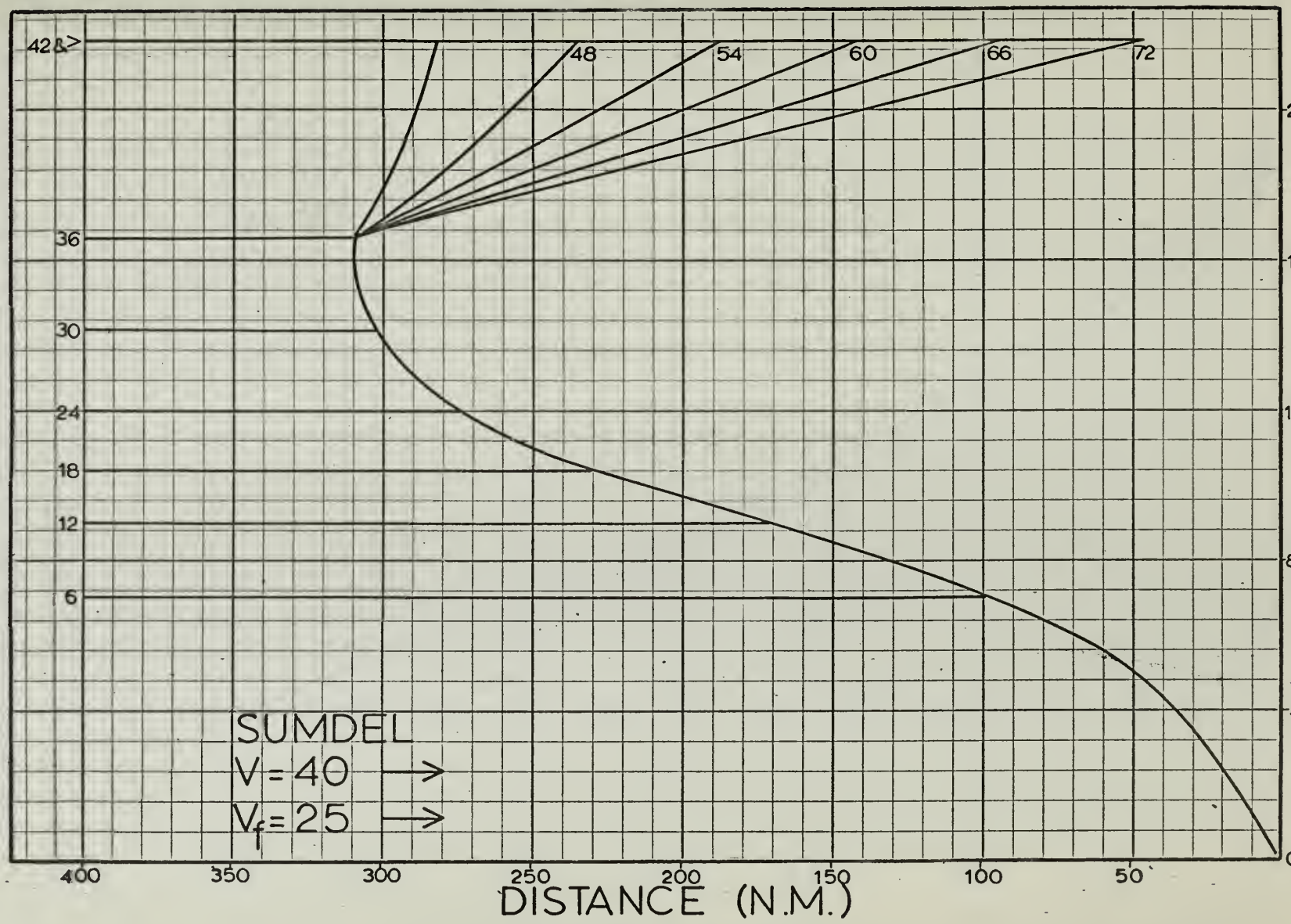



48
54
60
66
72
20
16
12
8
4
0
PERIOD (SEC)
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 40 →
Vf = 20 →

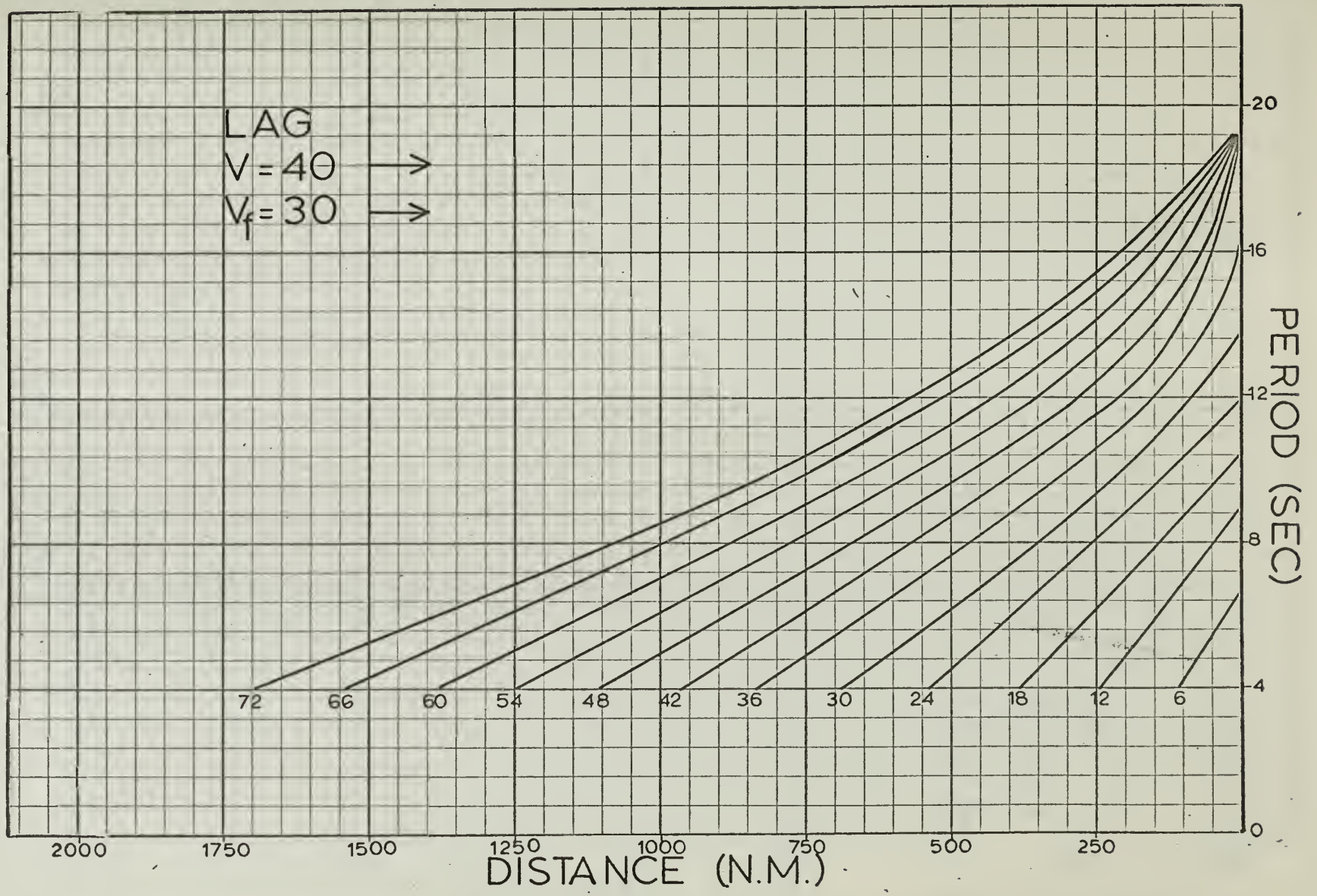

LAG
V = 40 →
V_f = 25 →
72
66
60
54
48
42
36
30
24
18
12
6
1600
1400
1200
1000
800
600
400
200
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)

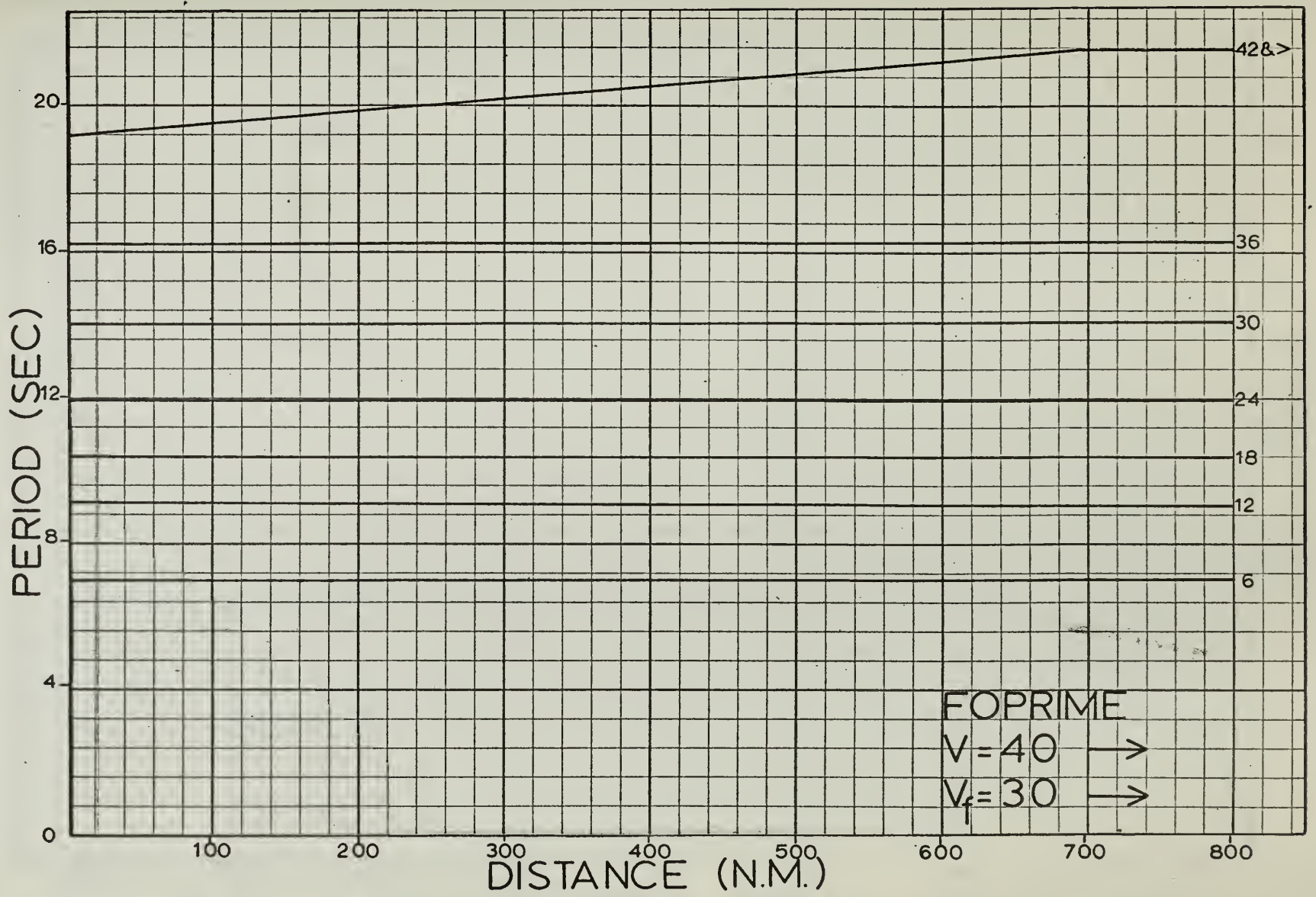

PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
42&>
36
30
24
18
12
6
FOPRIME
V = 40 →
Vf = 25 →



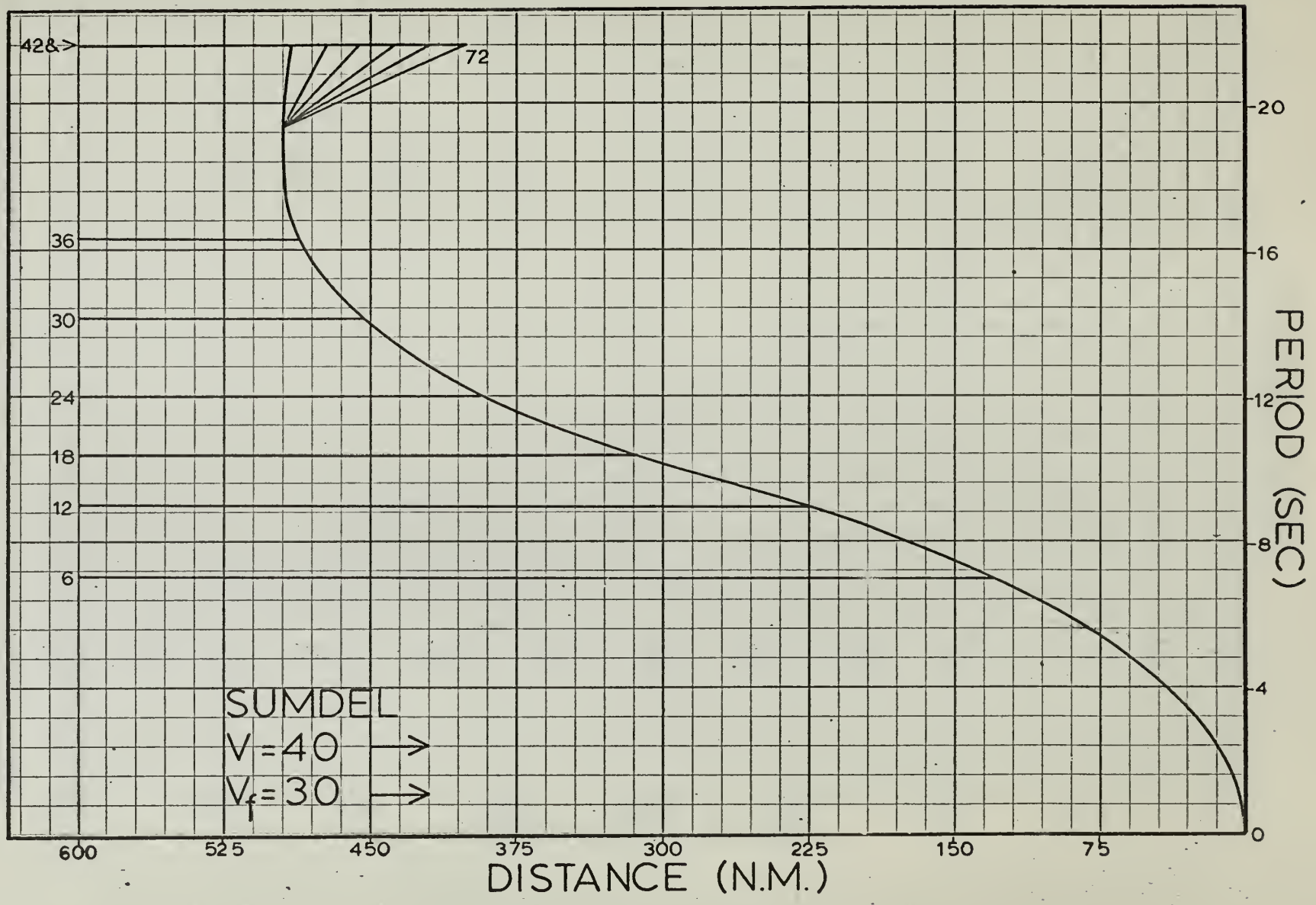

42&>
48
54
60
66
72
36
30
24
18
12
6
SUMDEL
V=40 →
Vf=25 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)



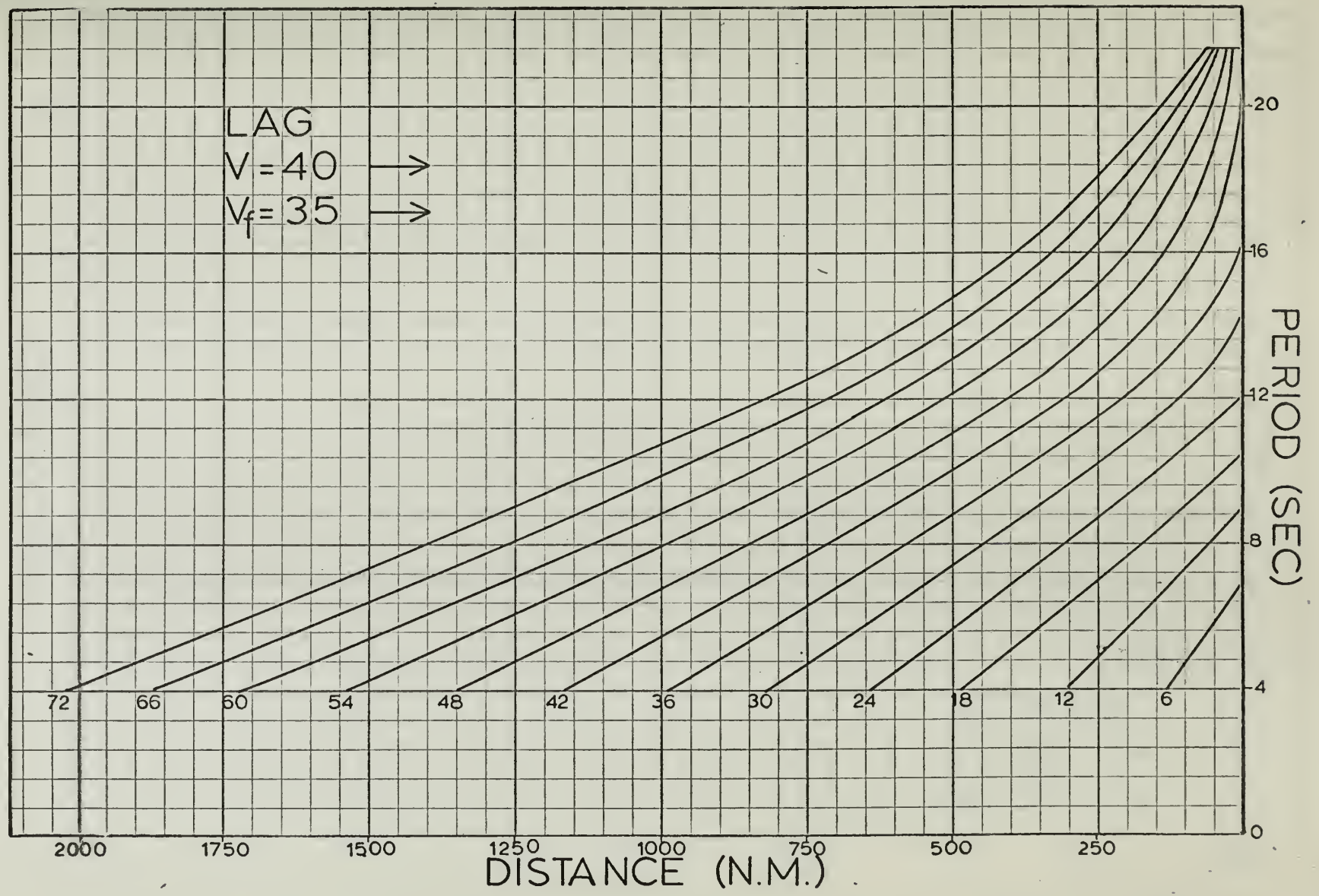

LAG
V = 40 →
Vf = 30 →
72
66
60
54
48
42
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)


PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
100
200
300
400
500
600
700
800
42&>
36
30
24
18
12
6
FOPRIME
V=40
Vf=30

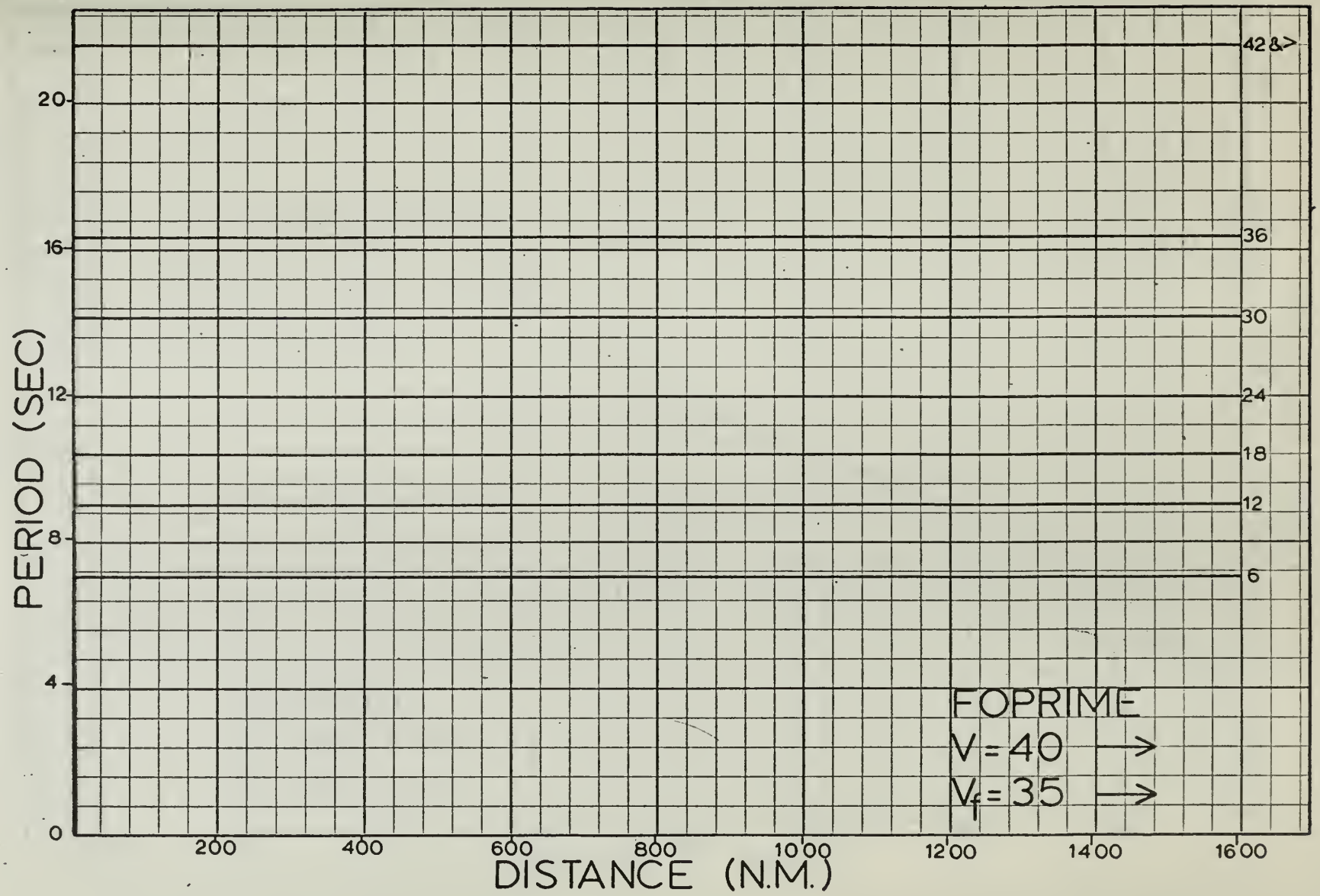



42&>
72
36
30
24
18
12
6
SUMDEL
V=40 →
V_f=30 →
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)

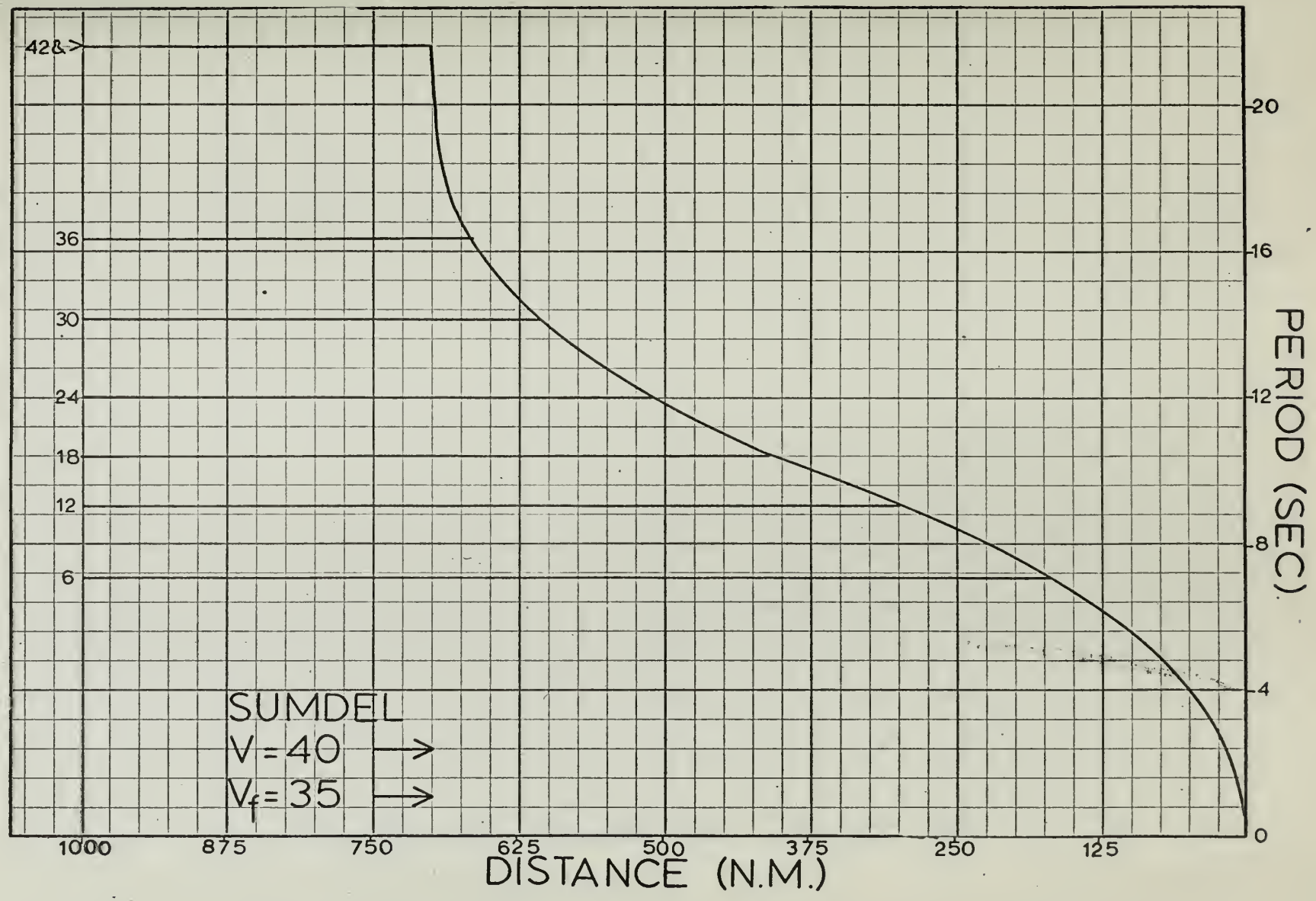


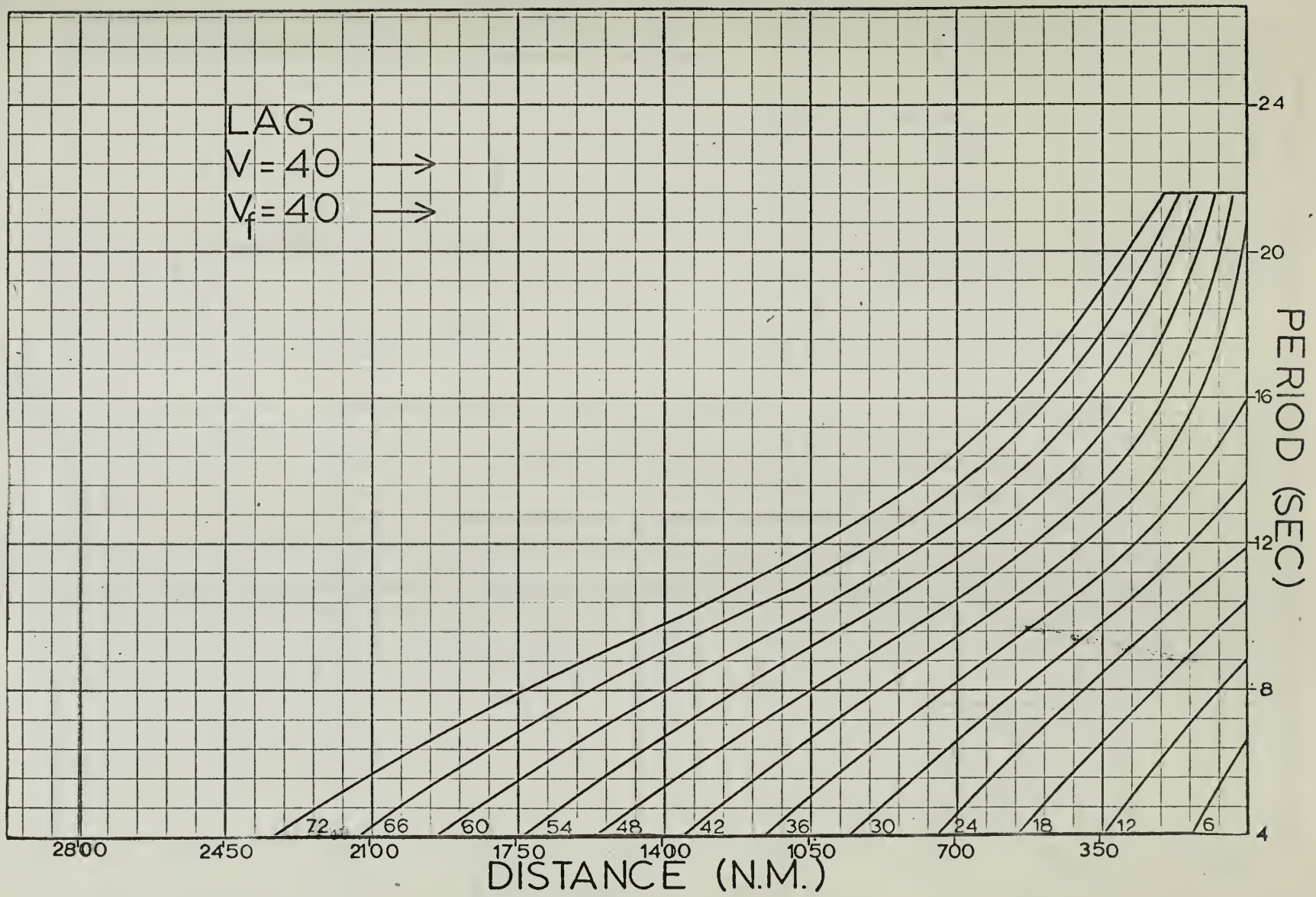

LAG
V = 40 →
V_f = 35 →
72
66
60
54
48
42
36
30
24
18
12
6
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

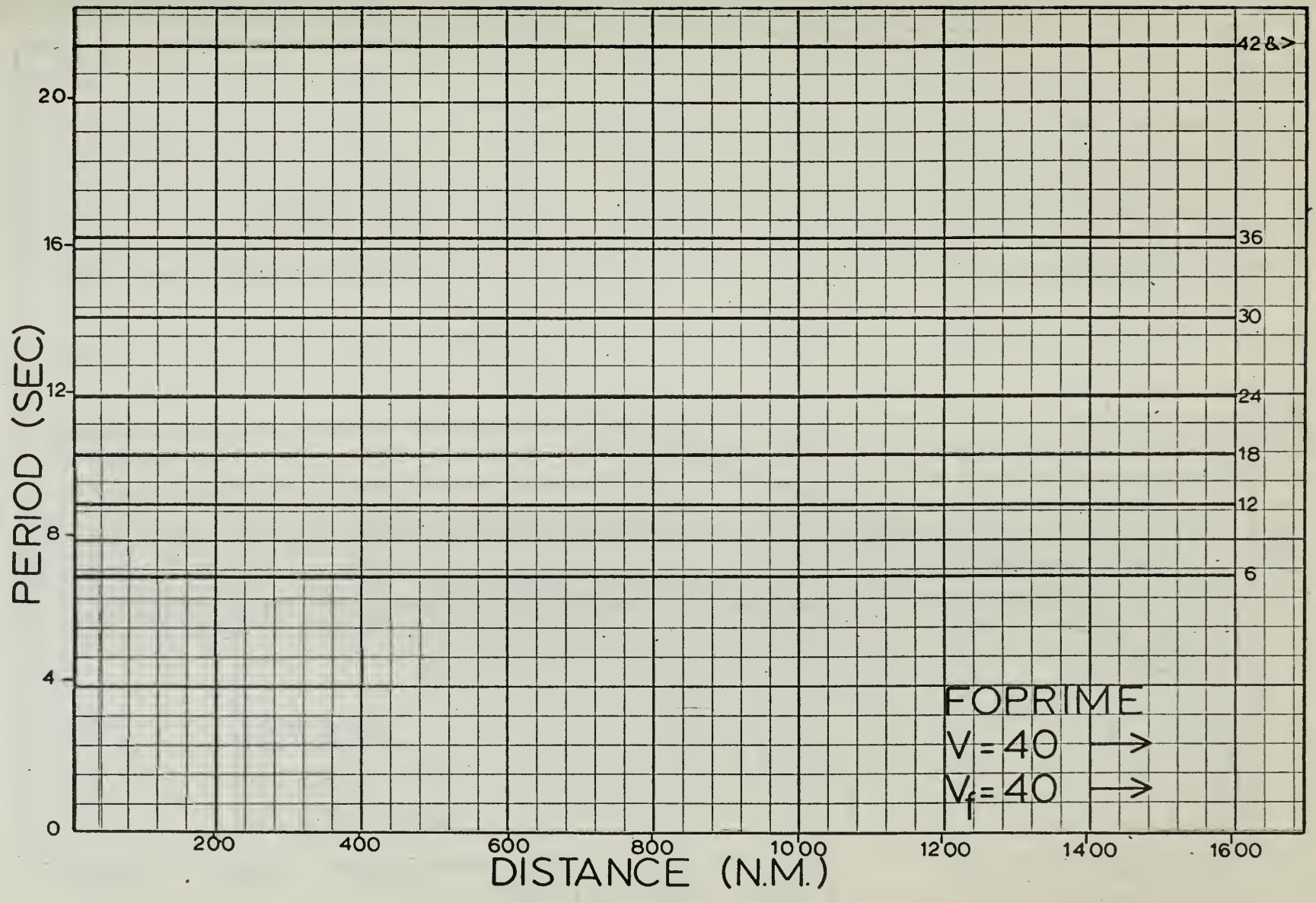



PERIOD (SEC)
0
4
8
12
16
20
42 &>
36
30
24
18
12
6
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
FOPRIME
V = 40 →
Vf = 35 →

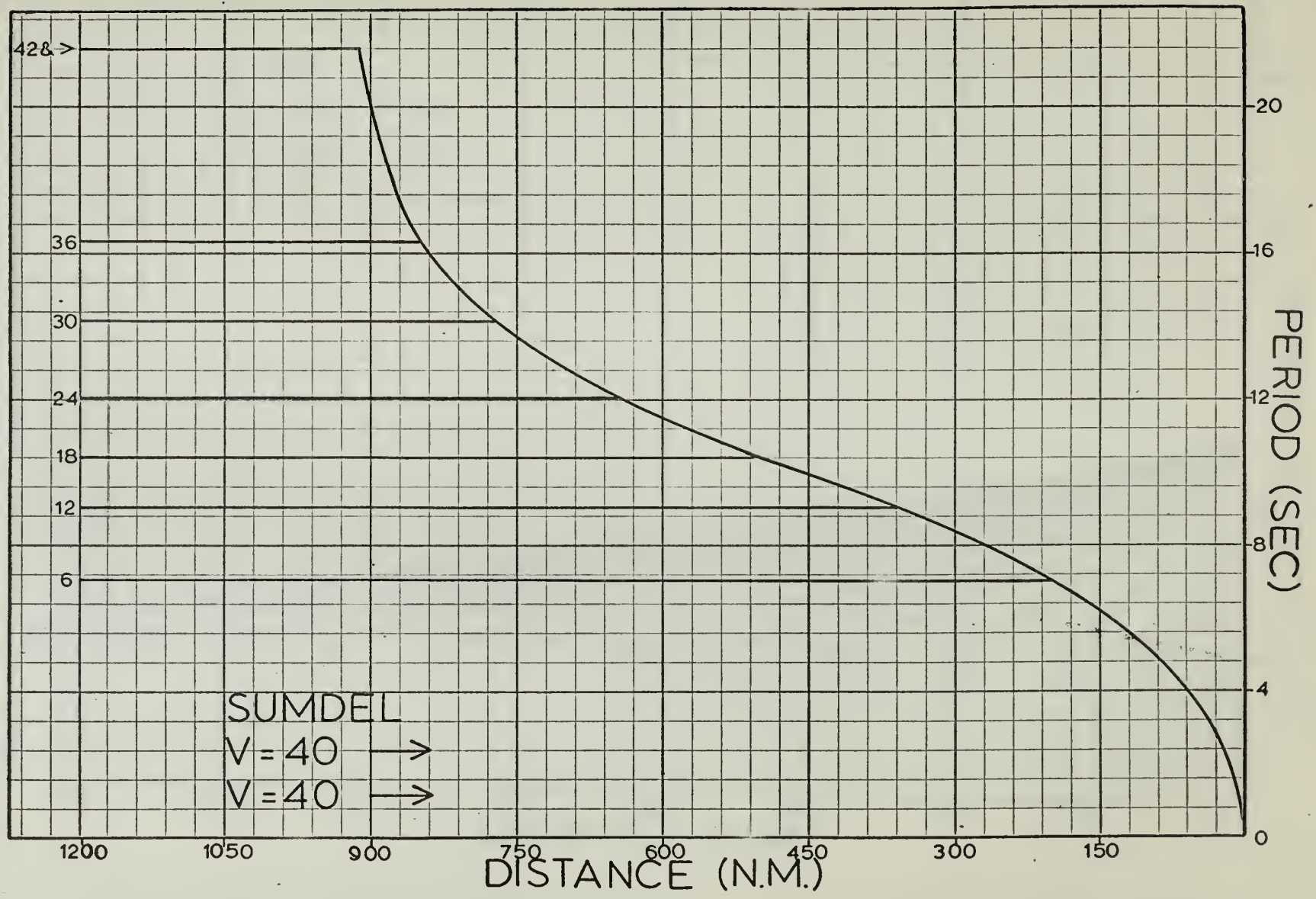



42&
36
30
24
18
12
6
SUMDEL
V = 40 →
Vf = 35 →
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC.)

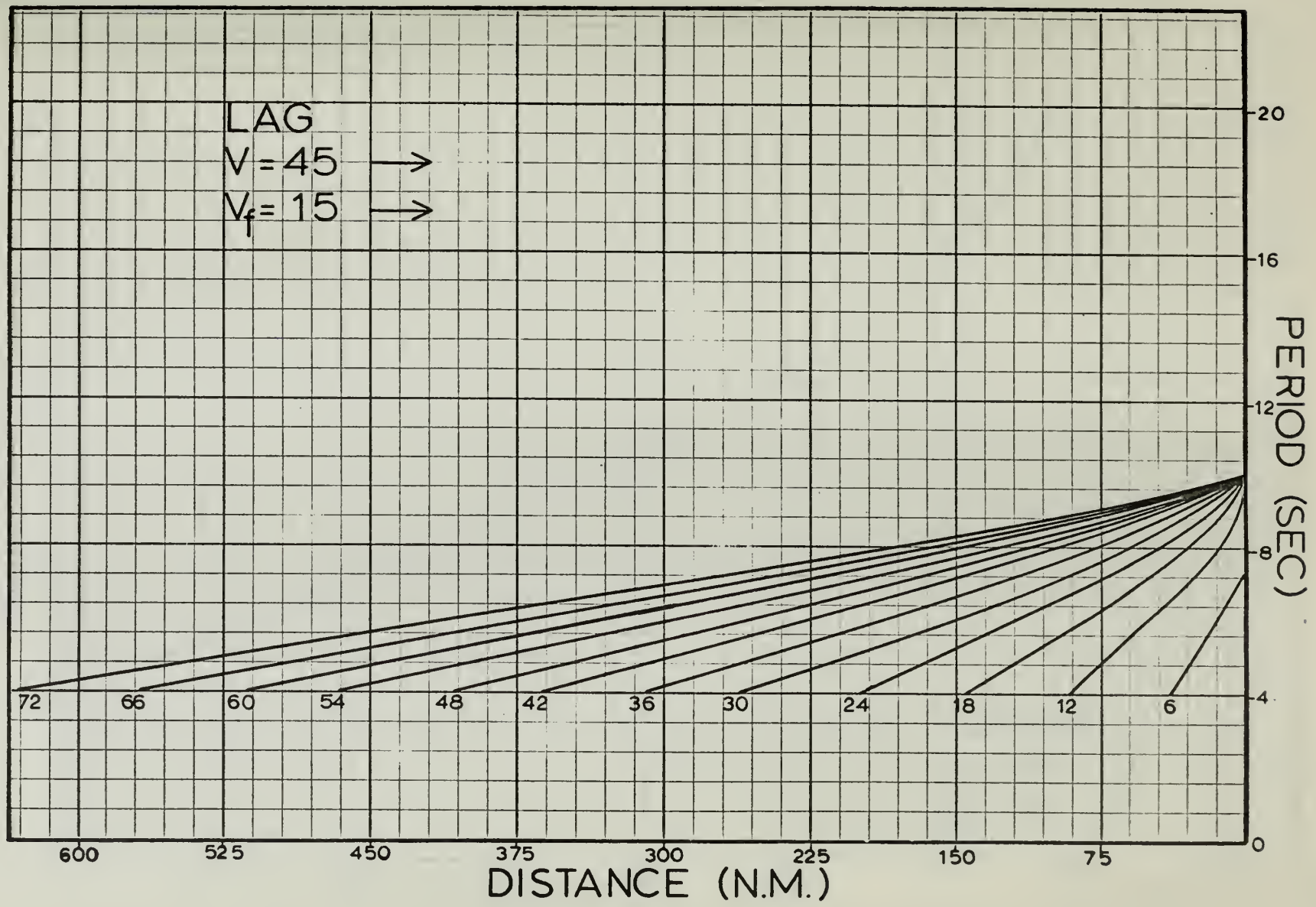

LAG
V = 40 →
Vf = 40 →
72
66
60
54
48
42
36
30
24
18
12
6
2800
2450
2100
1750
1400
1050
700
350
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC.)


PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
42 &>
36
30
24
18
12
6
FOPRIME
V = 40
Vf = 40

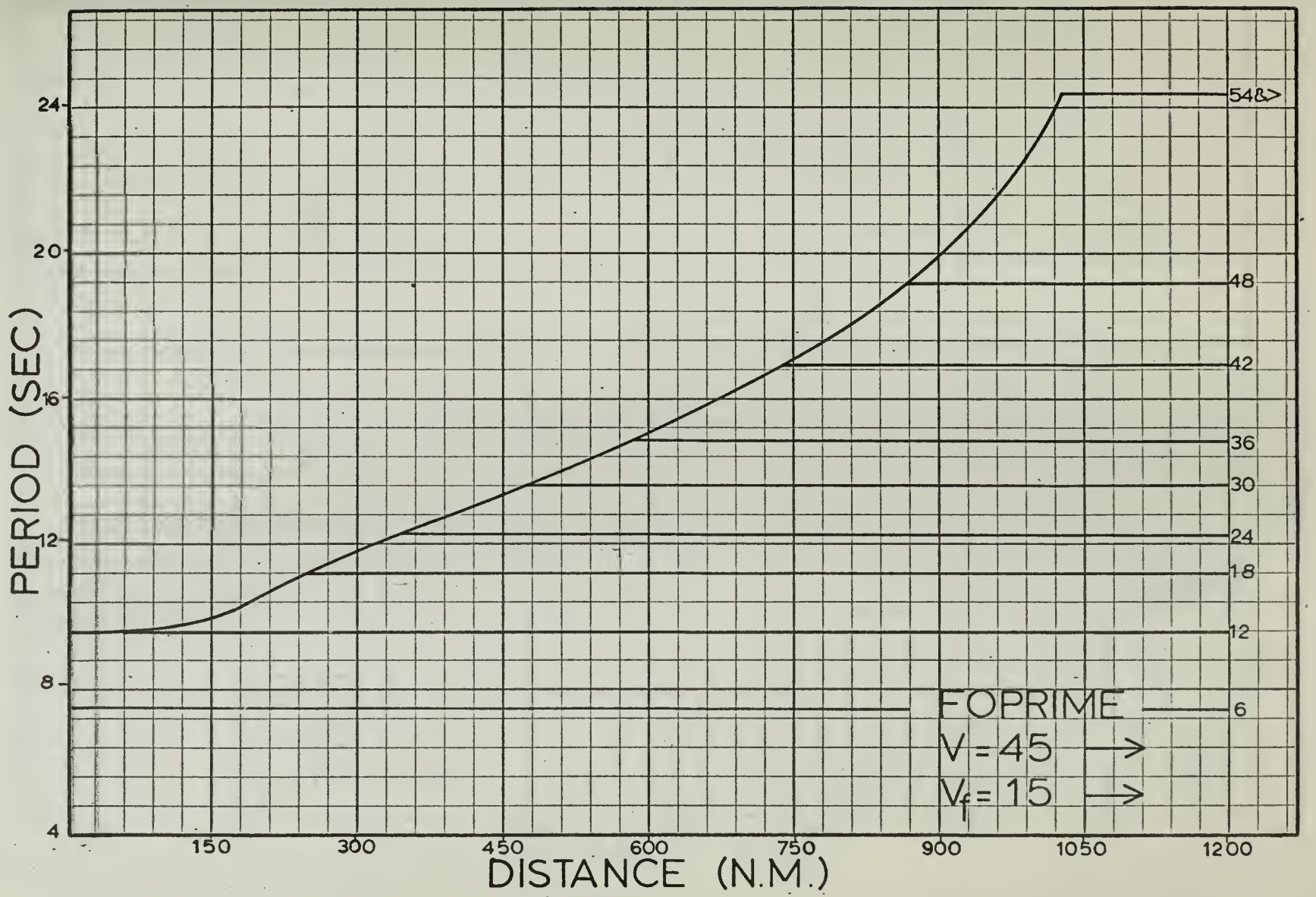



42&>
36
30
24
18
12
6
SUMDEL
V=40 →
V=40 →
1200
1050
900
750
600
450
300
150
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)

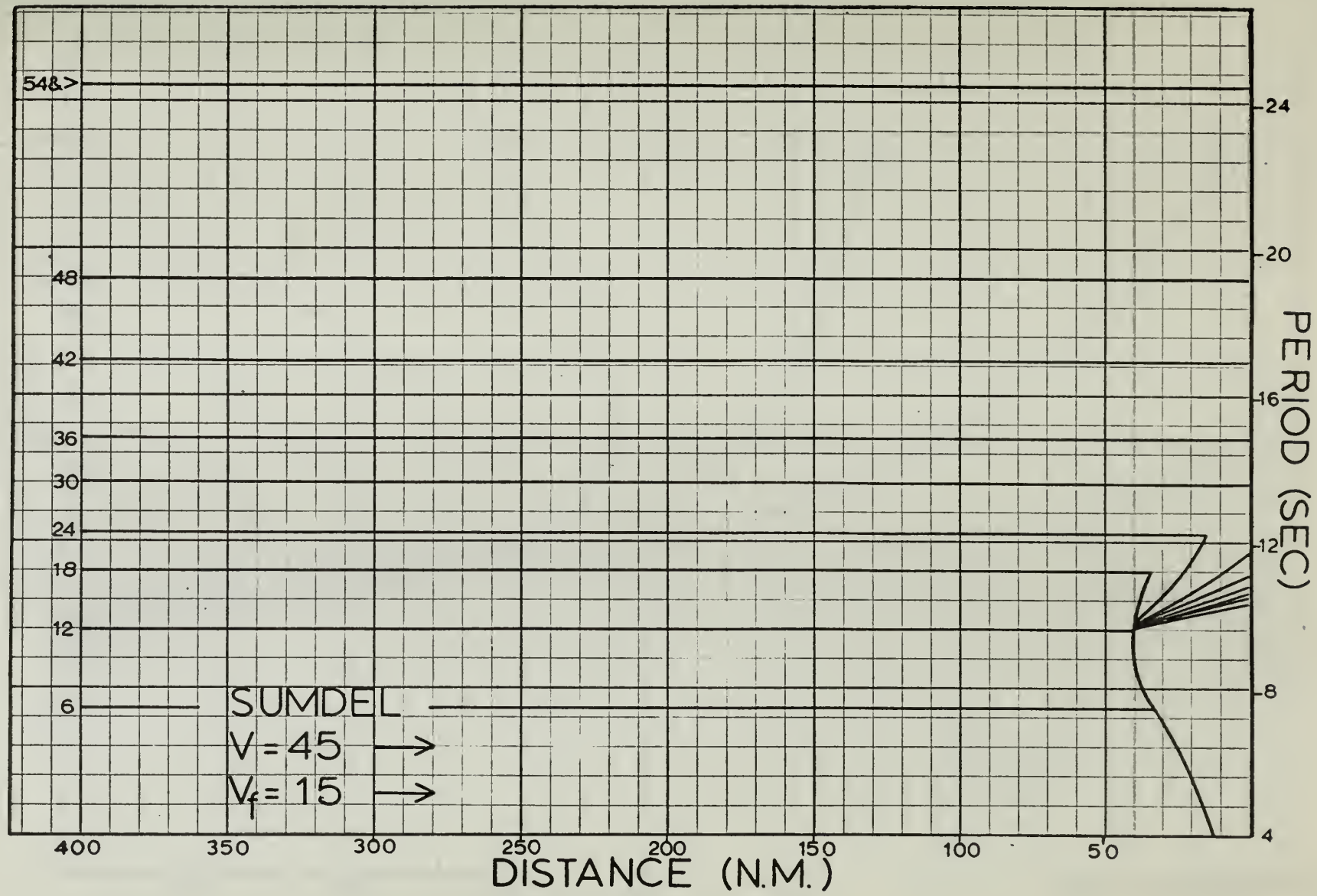



LAG
V = 45
V_f = 15
72
66
60
54
48
42
36
30
24
18
12
6
600
525
450
375
300
225
150
75
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)




PERIOD (SEC)
24
20
16
12
8
4
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)
548>
48
42
36
30
24
18
12
6
FOPRIME
V = 45 →
Vf = 15 →

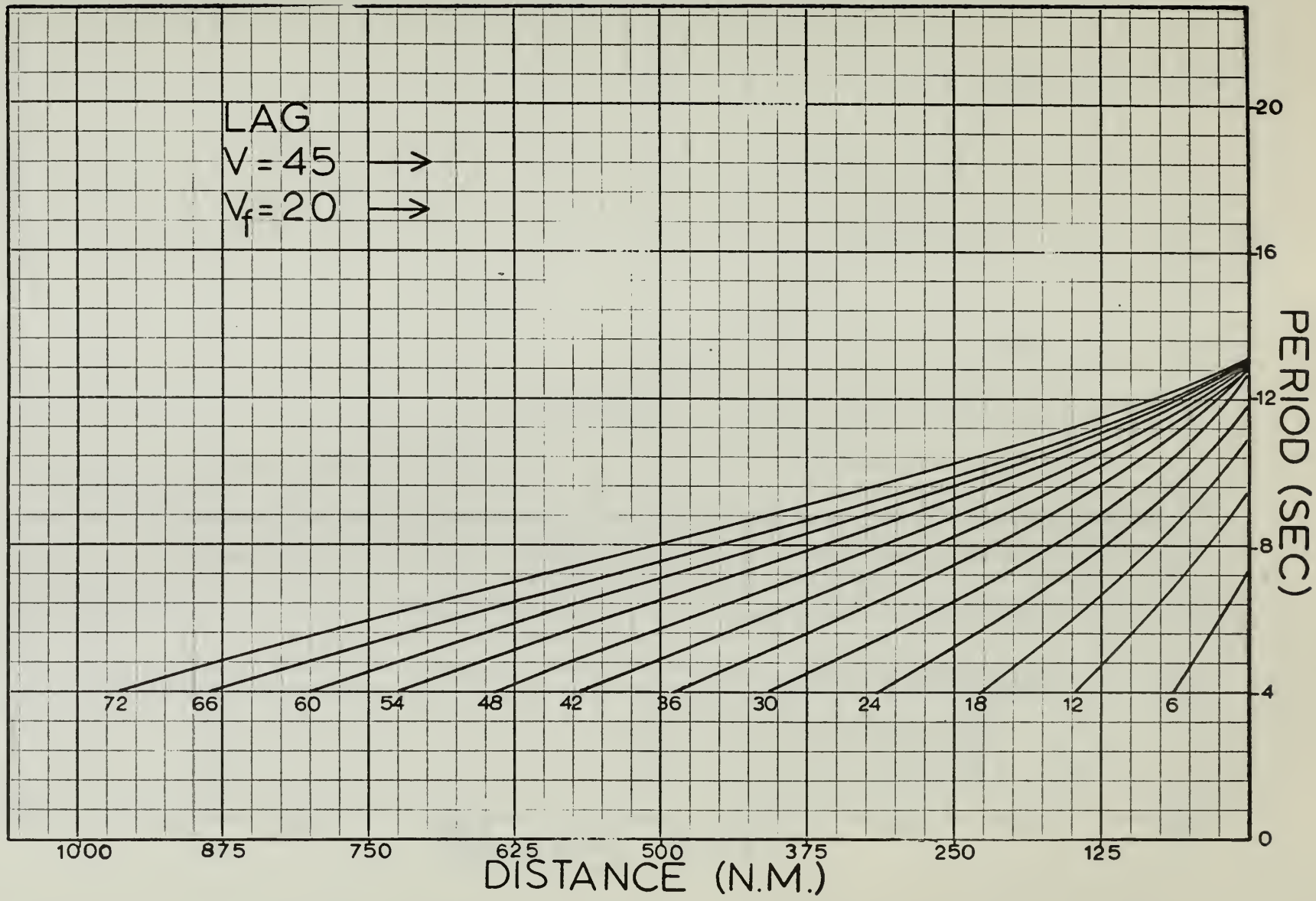



54&>
48
42
36
30
24
18
12
6
SUMDEL
V = 45
Vf = 15
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

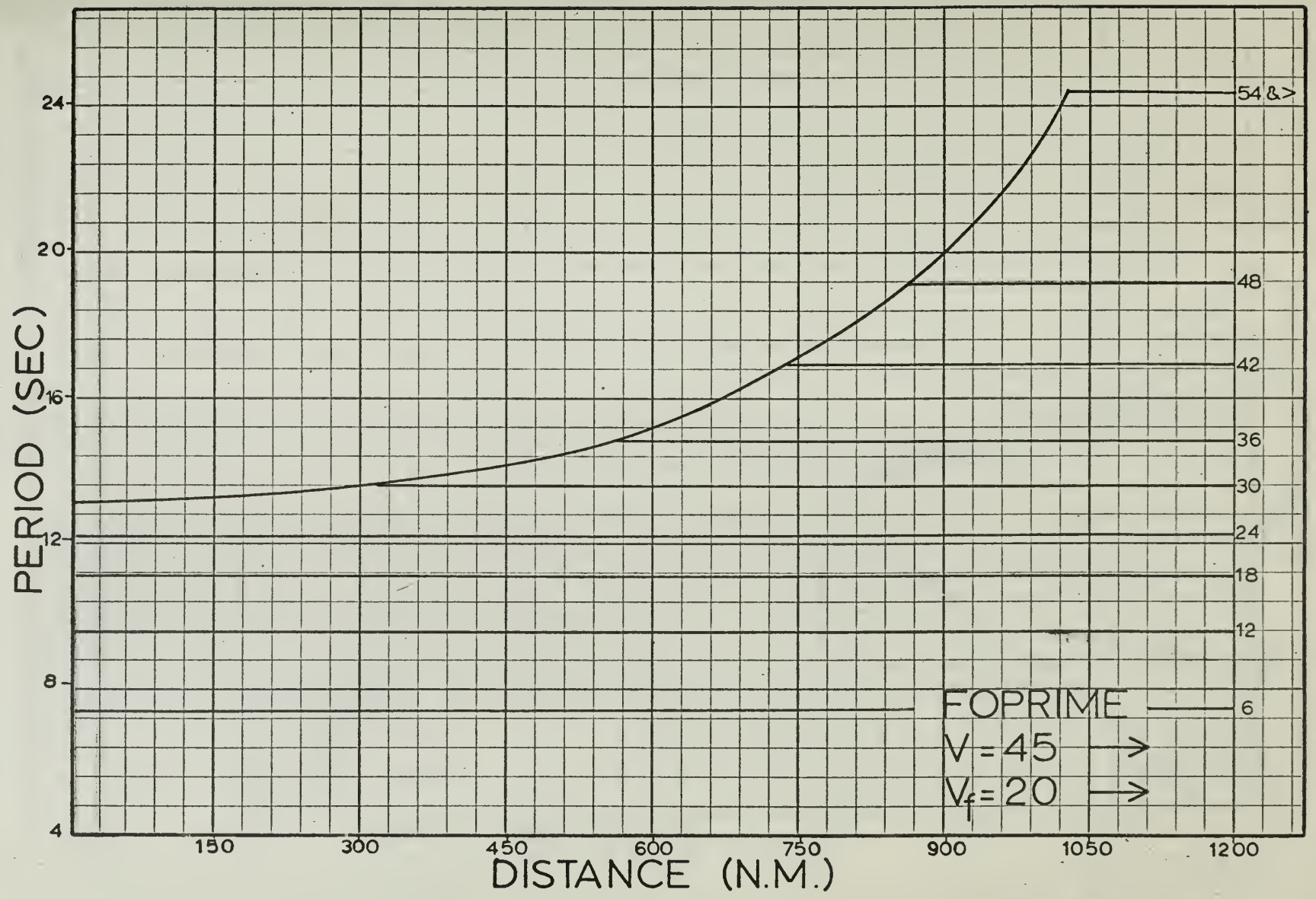



PERIOD (SEC)
24
20
16
12
8
4
54
60
66
72
48
42
36
30
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 45
Vf = 15

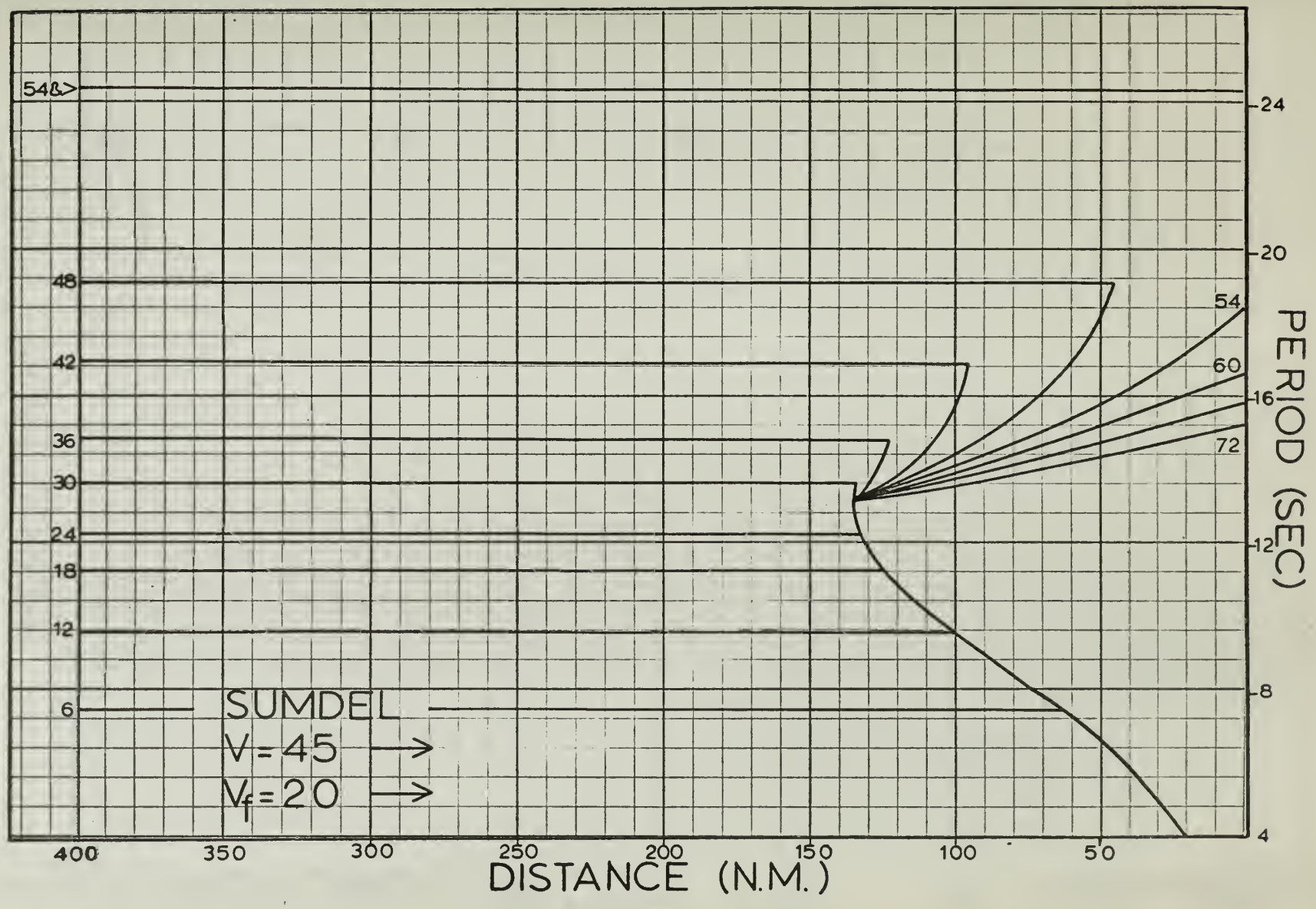



LAG
V = 45 →
V_f = 20 →
72
66
60
54
48
42
36
30
24
18
12
6
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

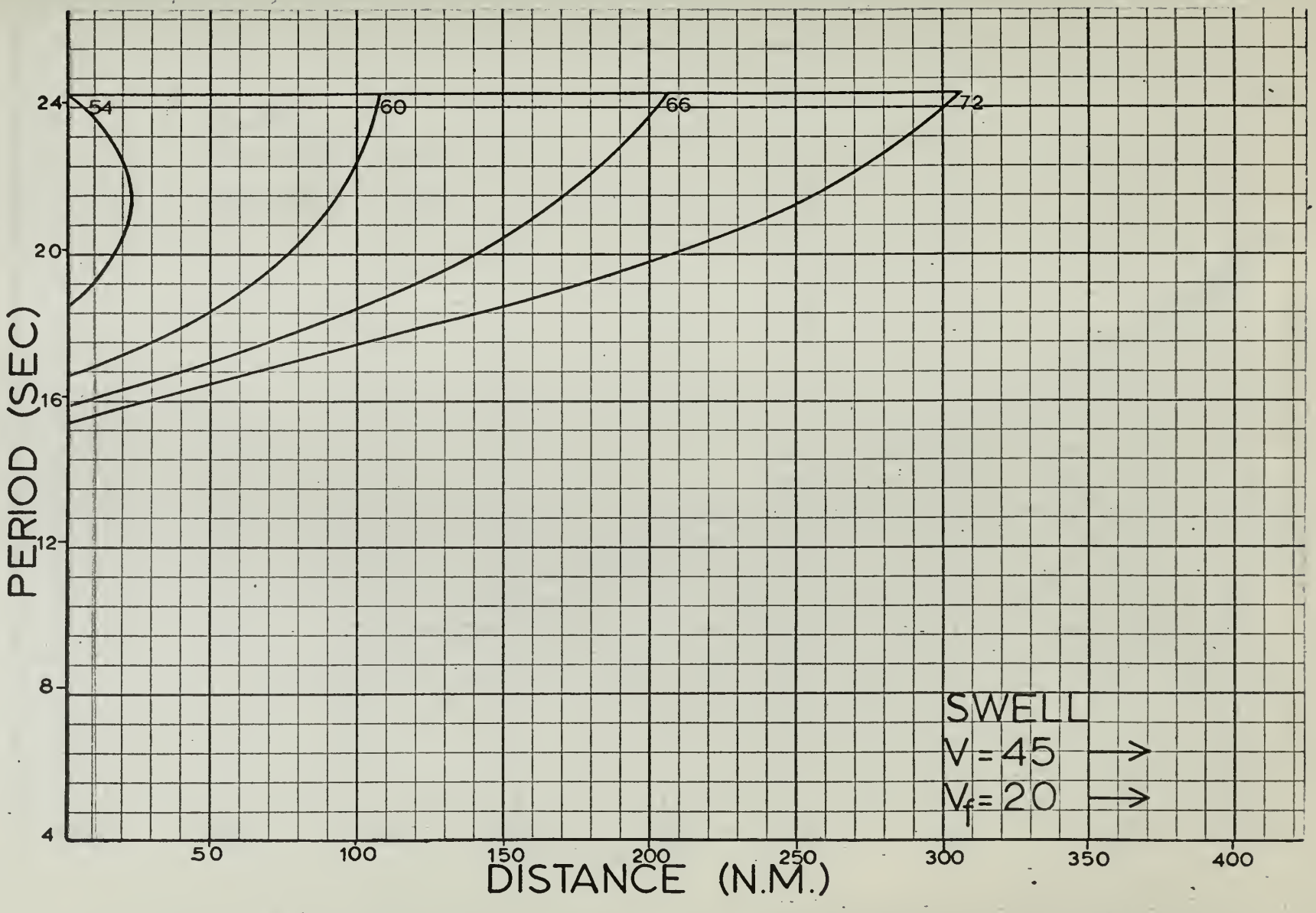



PERIOD (SEC)
24
20
16
12
8
4
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)
54 &>
48
42
36
30
24
18
12
6
FOPRIME
V = 45
Vf = 20

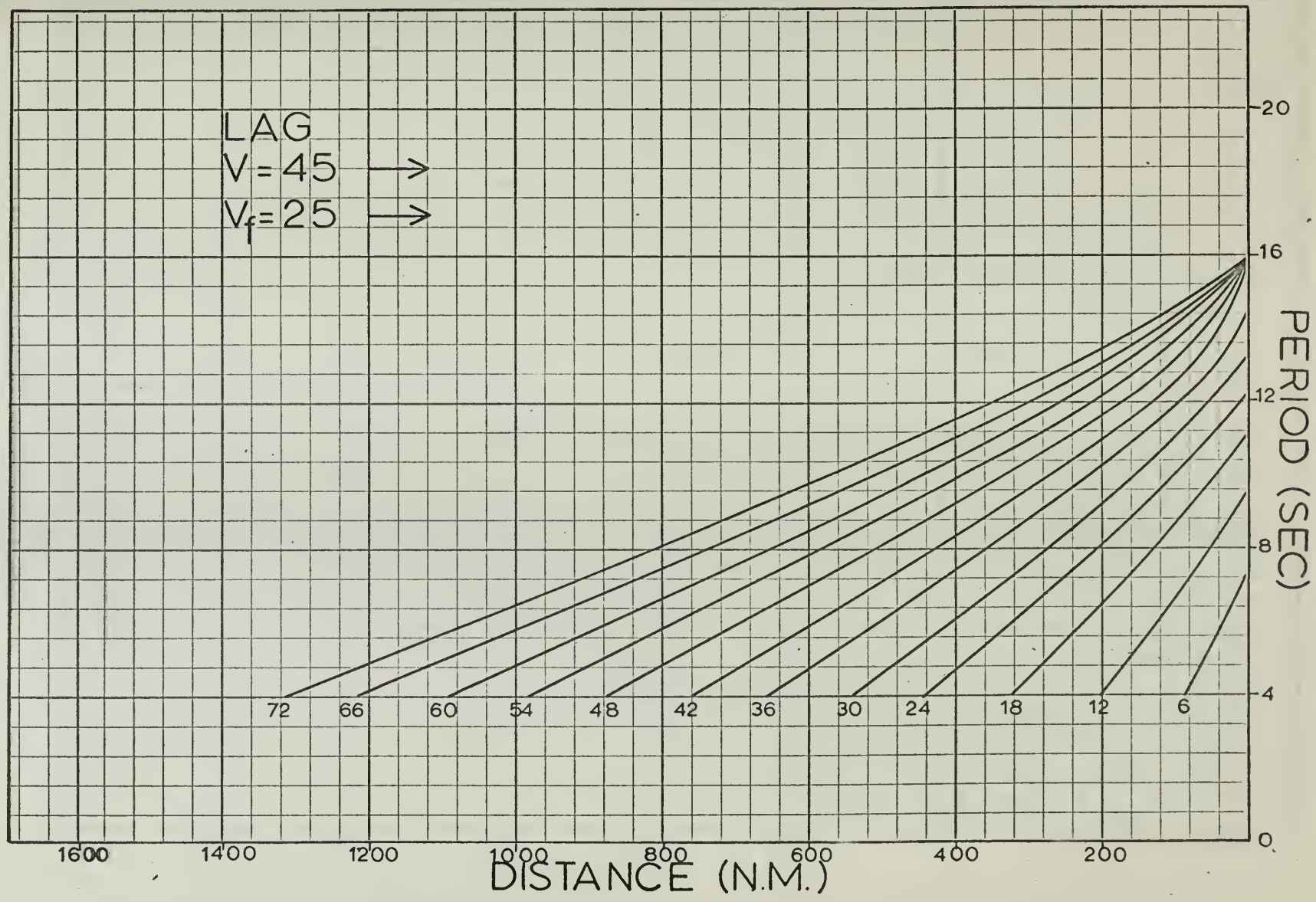


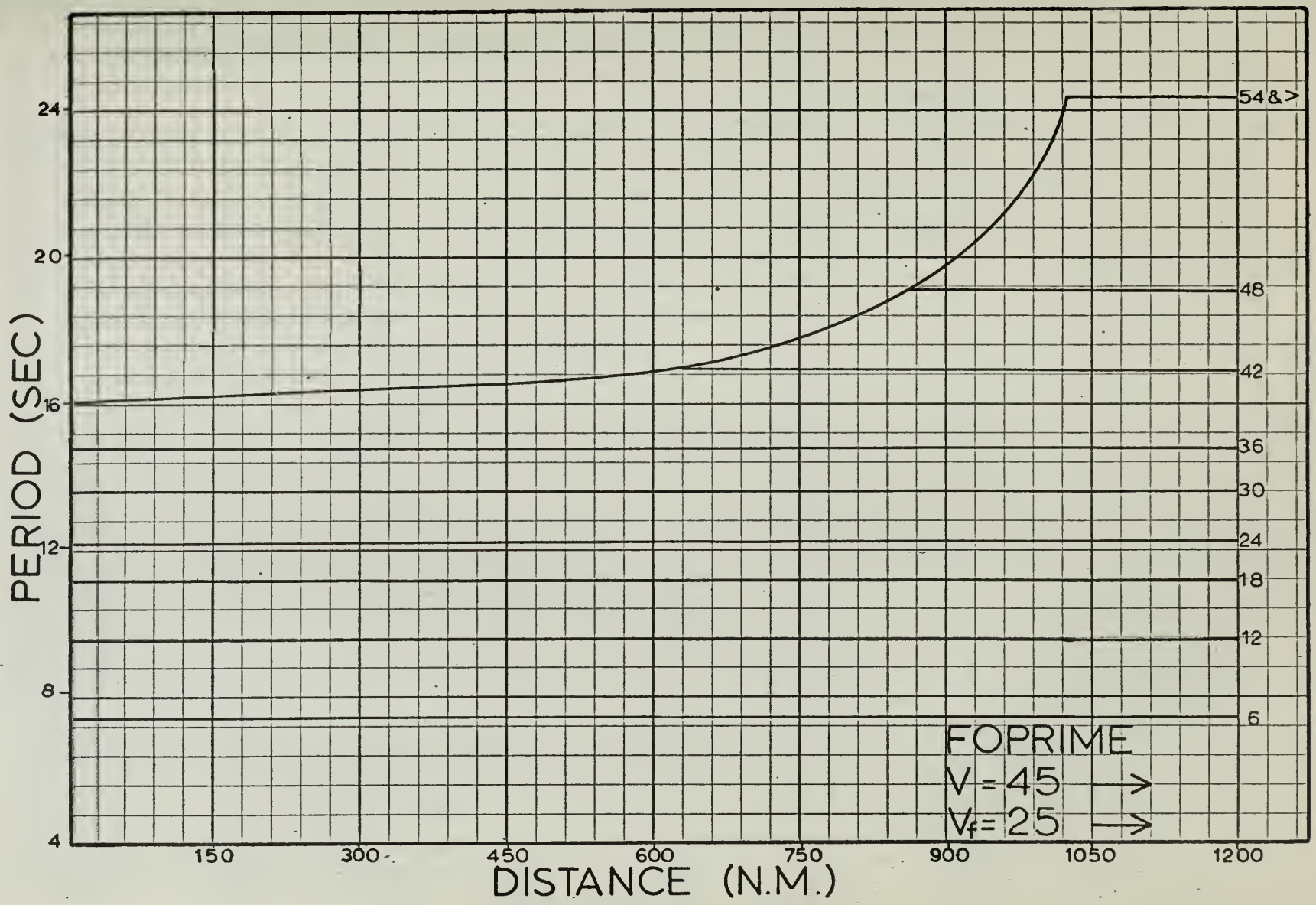

54&>
48
42
36
30
24
18
12
6
SUMDEL
V=45 →
Vf=20 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)
54
60
72



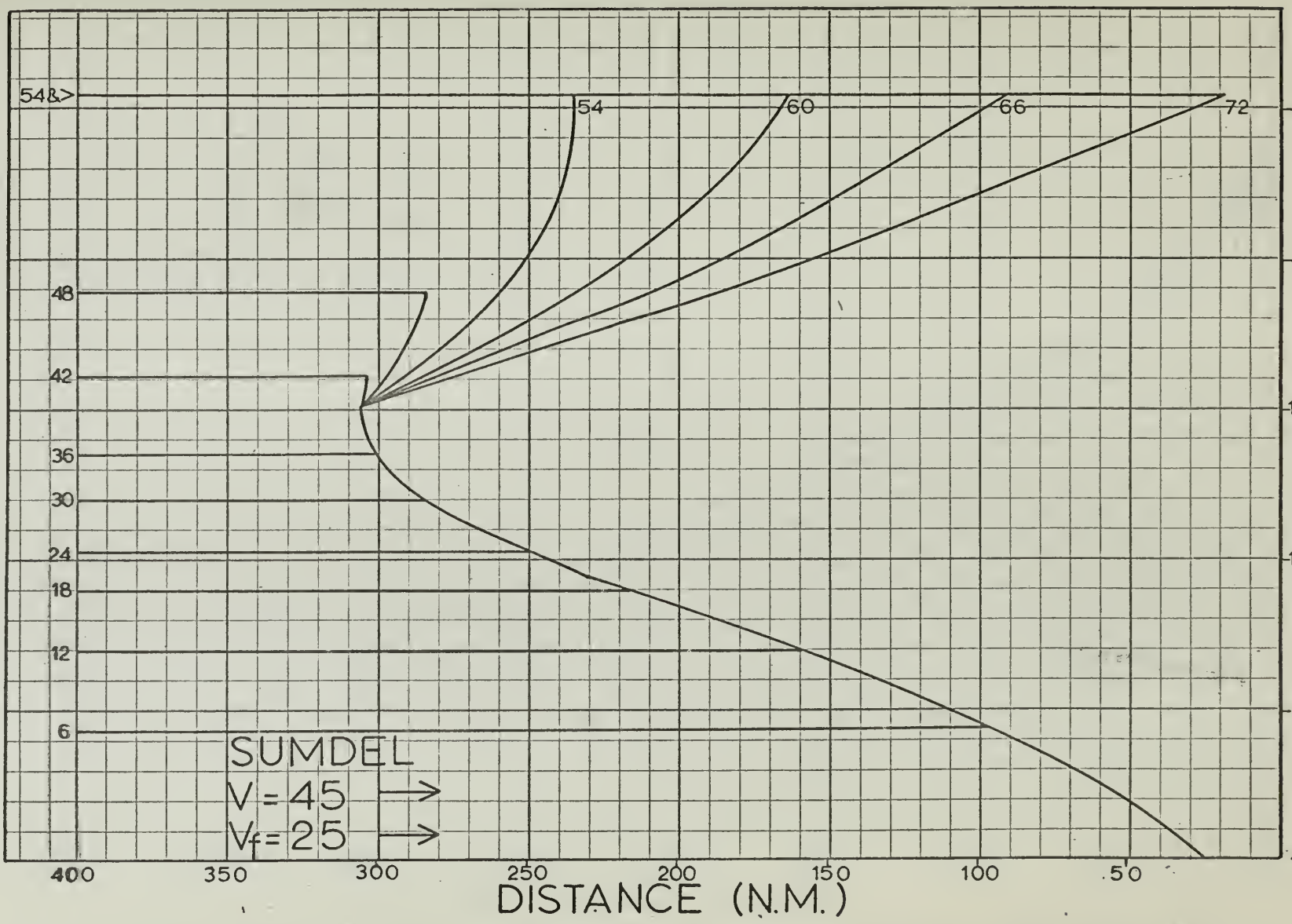

54
60
66
72
24
20
16
12
8
4
PERIOD (SEC)
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 45
Vf = 20

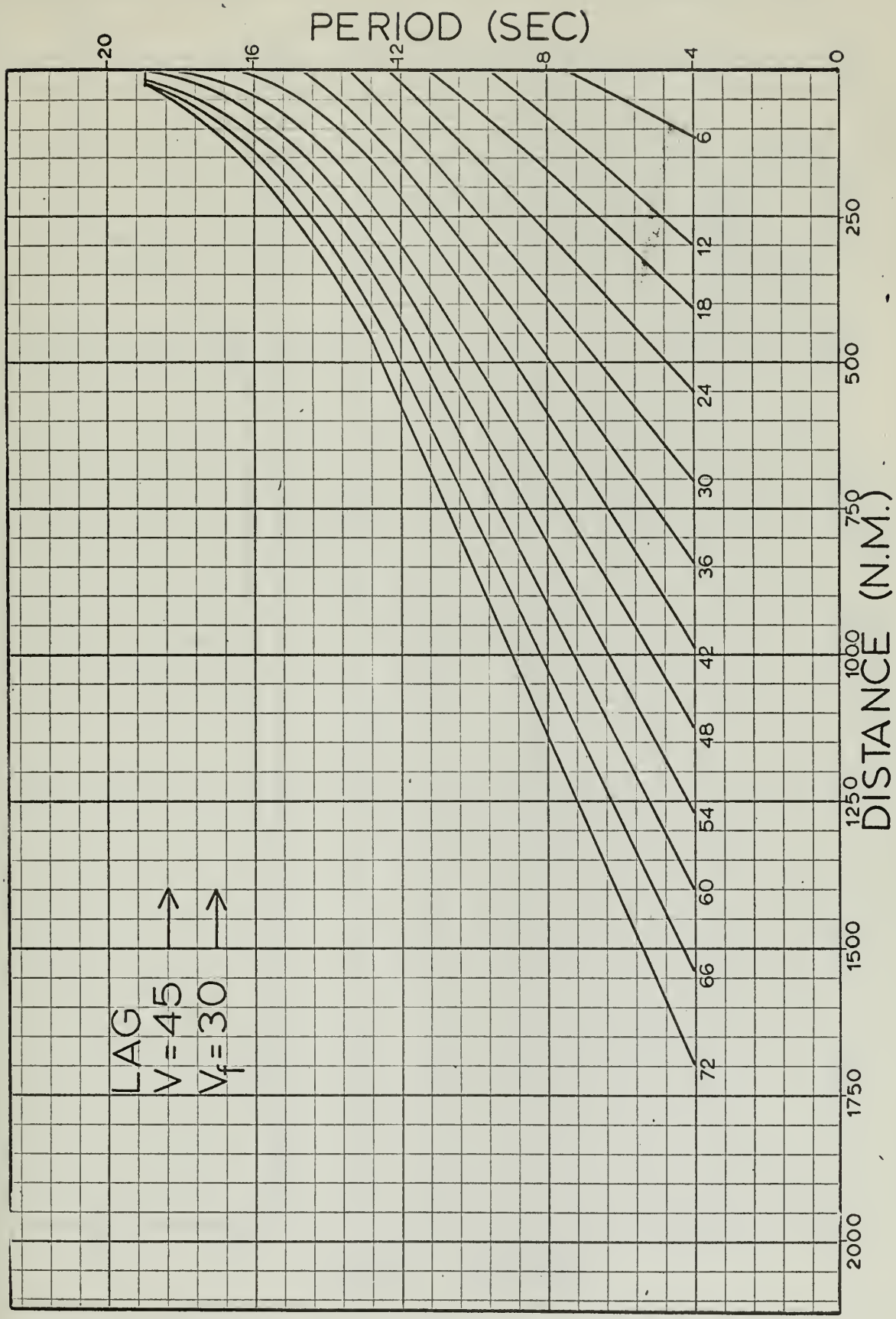


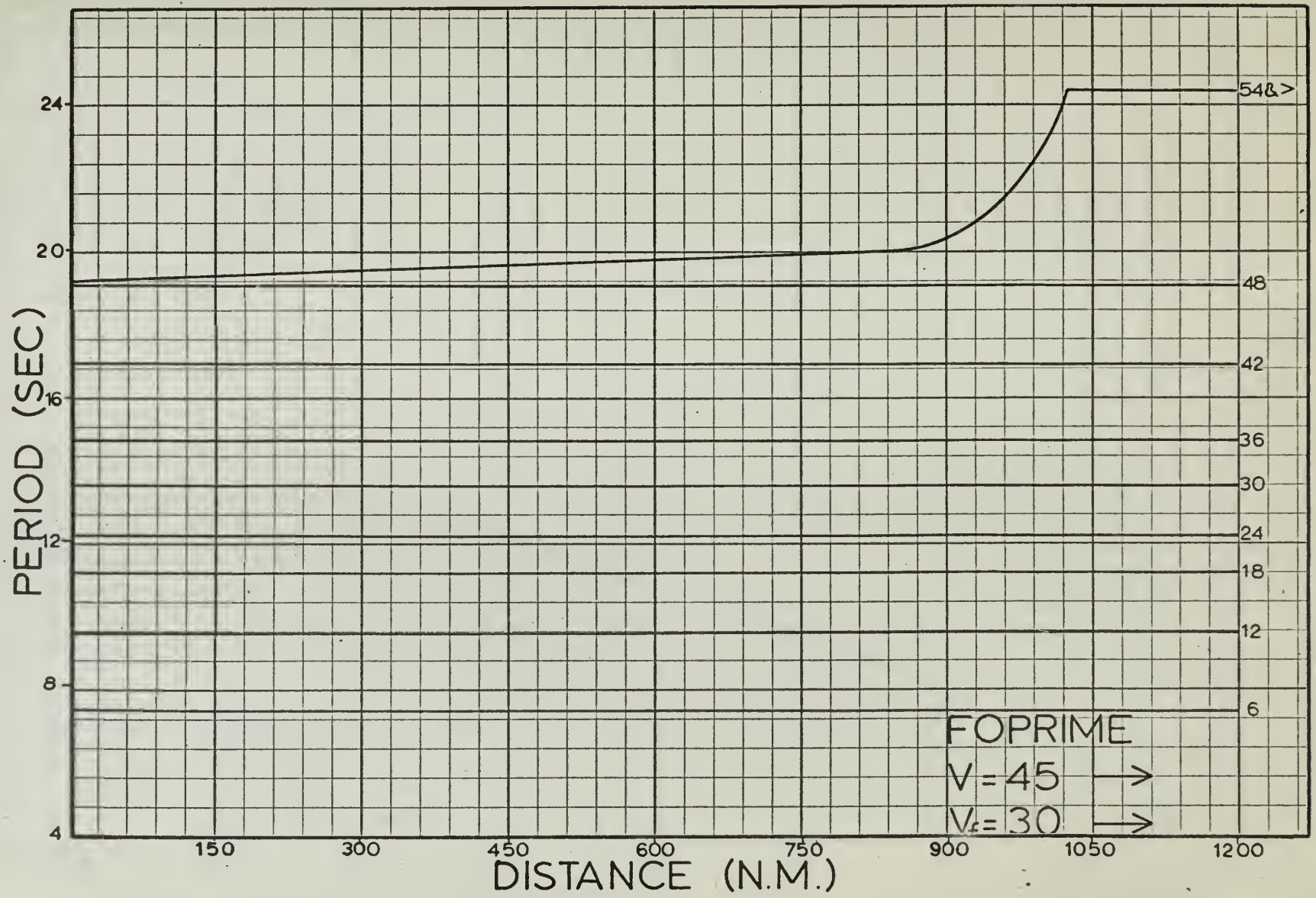

LAG
V = 45 →
Vf = 25 →
72
66
60
54
48
42
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
1600
1400
1200
1000
800
600
400
200
DISTANCE (N.M.)

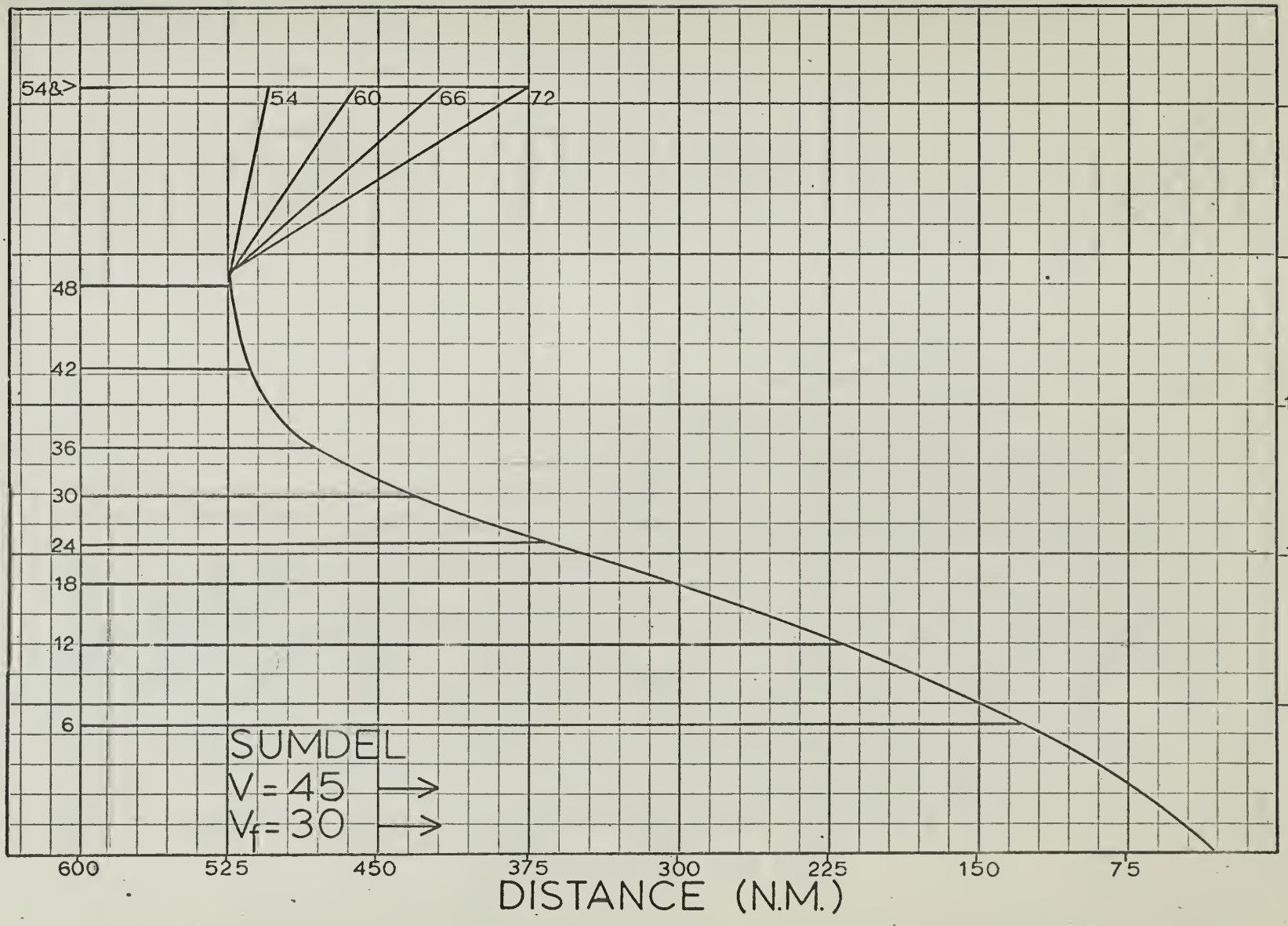

PERIOD (SEC)
24
20
16
12
8
4
54 &>
48
42
36
30
24
18
12
6
FOPRIME
V = 45 →
Vf = 25 →
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)

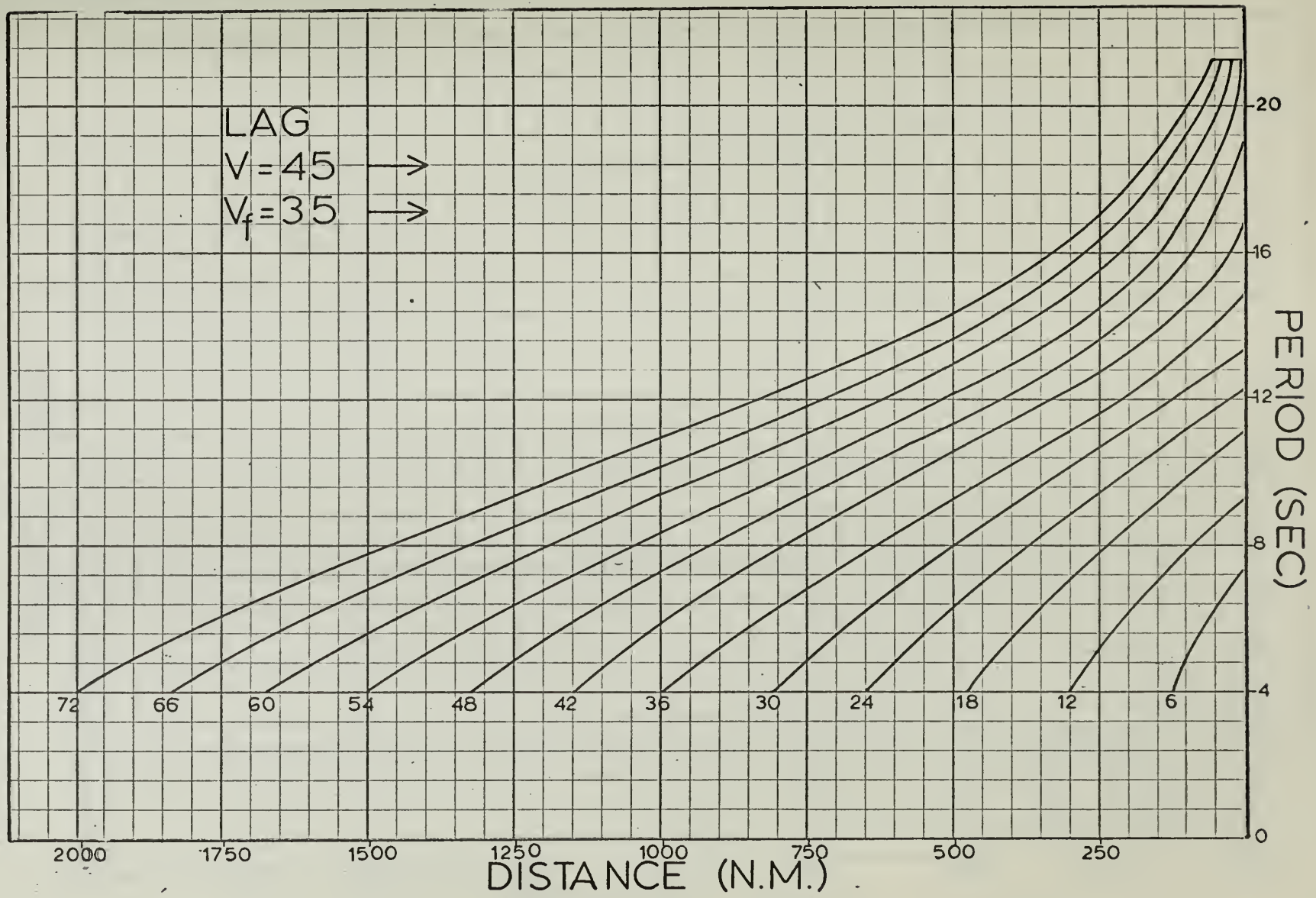



54&>
48
42
36
30
24
18
12
6
54
60
66
72
24
20
16
12
8
4
PERIOD (SEC)
SUMDEL
V = 45 →
Vf = 25 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)

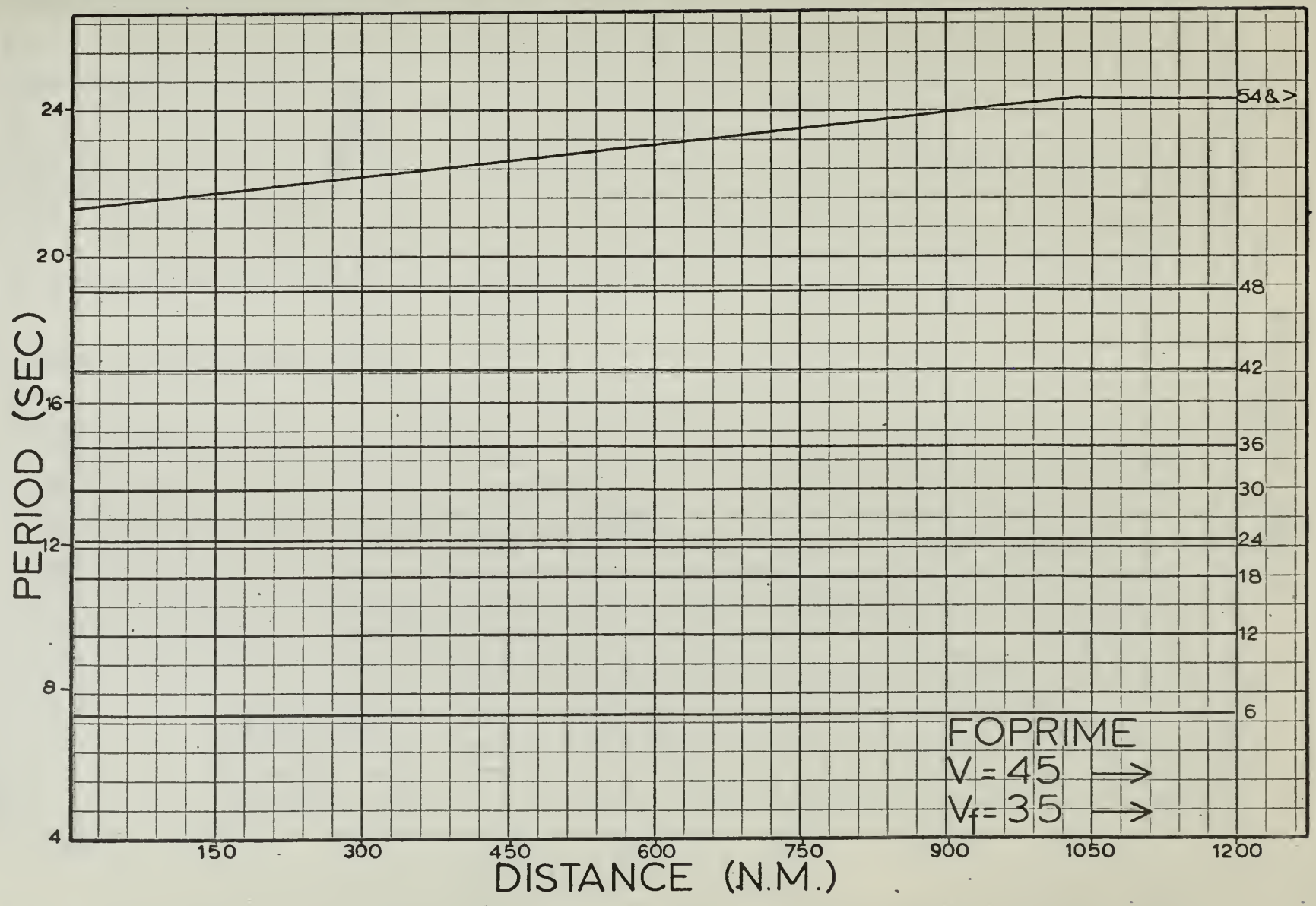

PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
250
500
750
1000
1250
1500
1750
2000
DISTANCE (N.M.)
LAG
V = 45
Vf = 30


PERIOD (SEC)
24
20
16
12
8
4
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)
54&>
48
42
36
30
24
18
12
6
FOPRIME
V=45 →
V=30 →

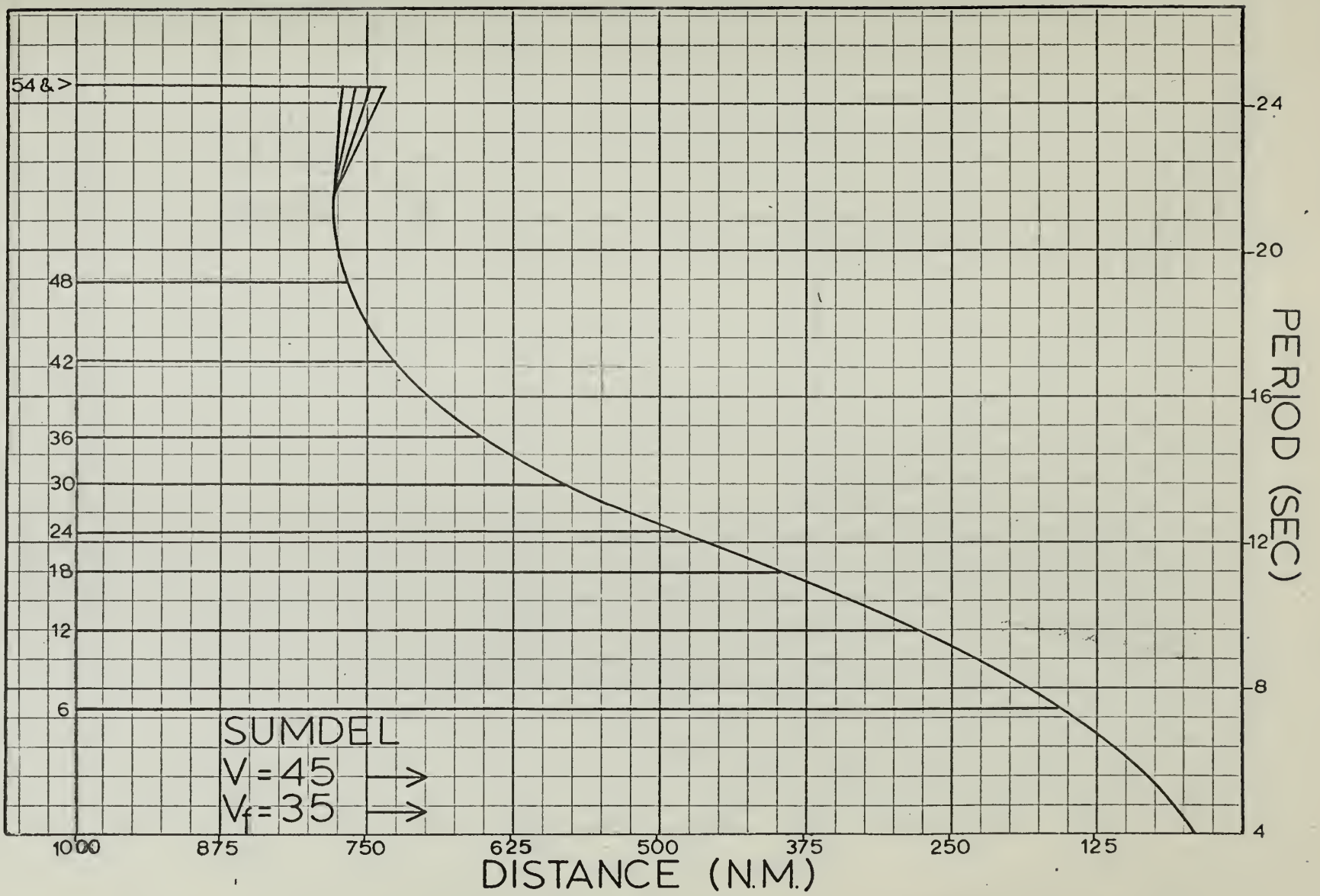

54&>
54
60
66
72
48
42
36
30
24
18
12
6
SUMDEL
V = 45
Vf = 30
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

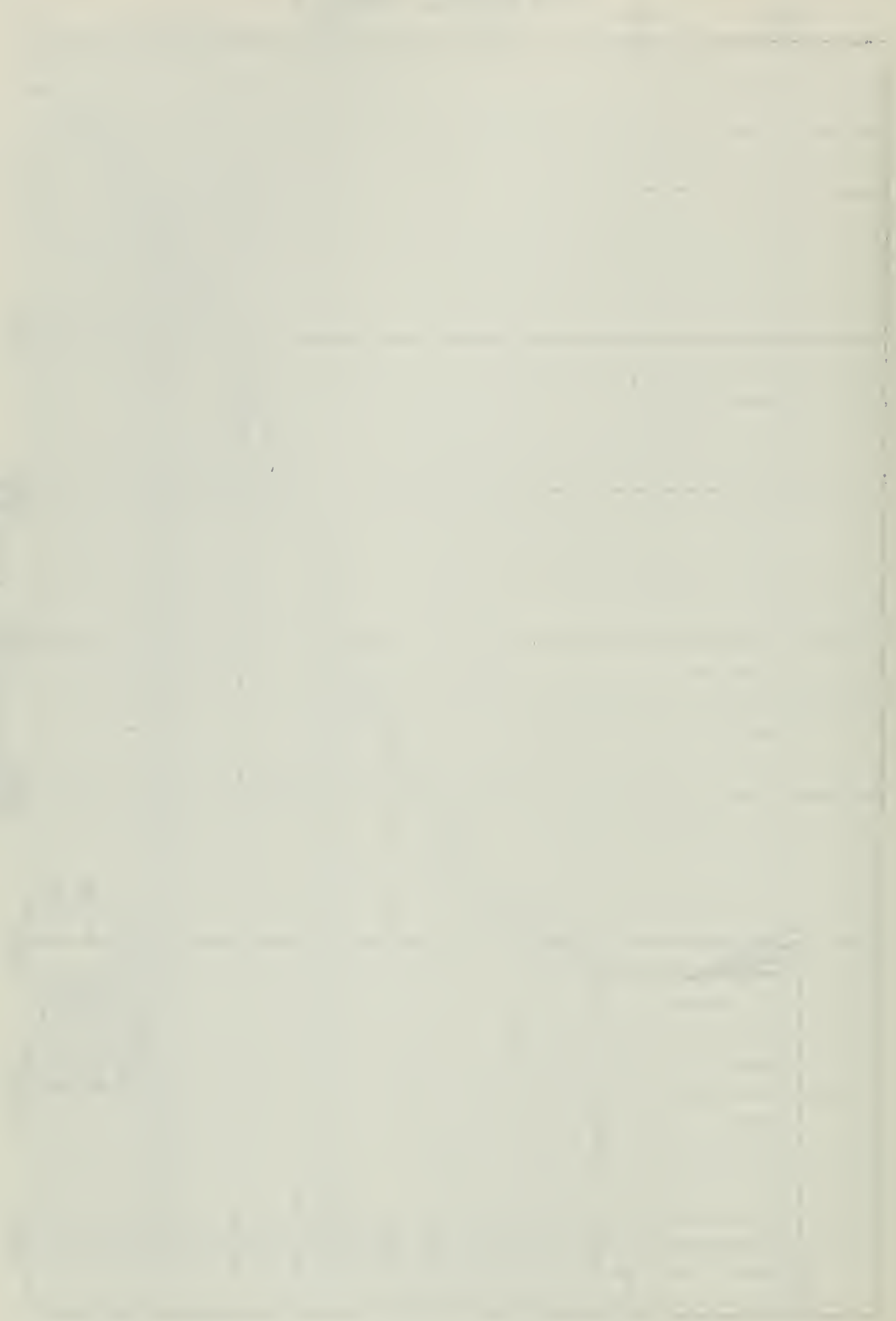

LAG
V = 45
V_f = 35
72
66
60
54
48
42
36
30
24
18
12
6
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

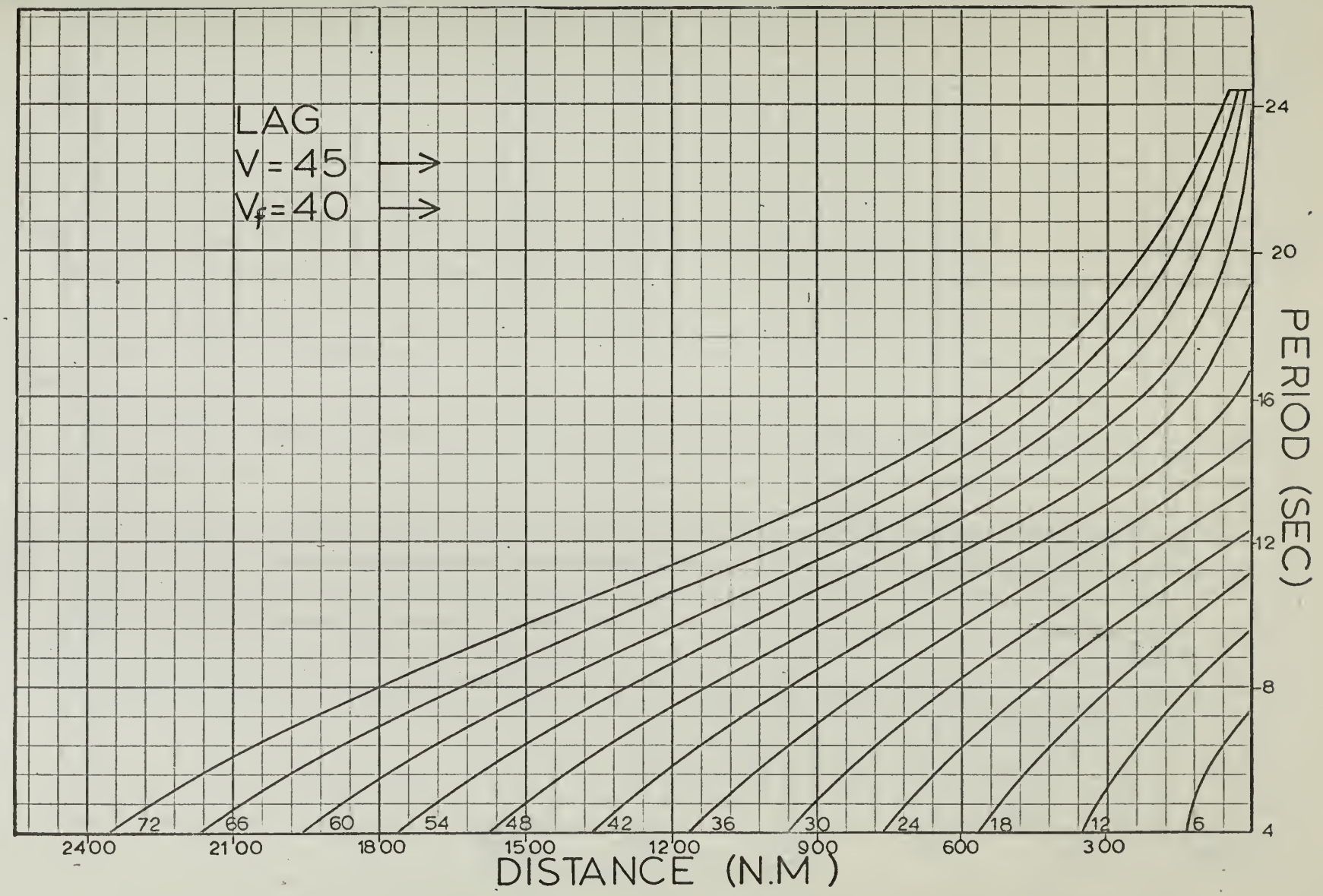


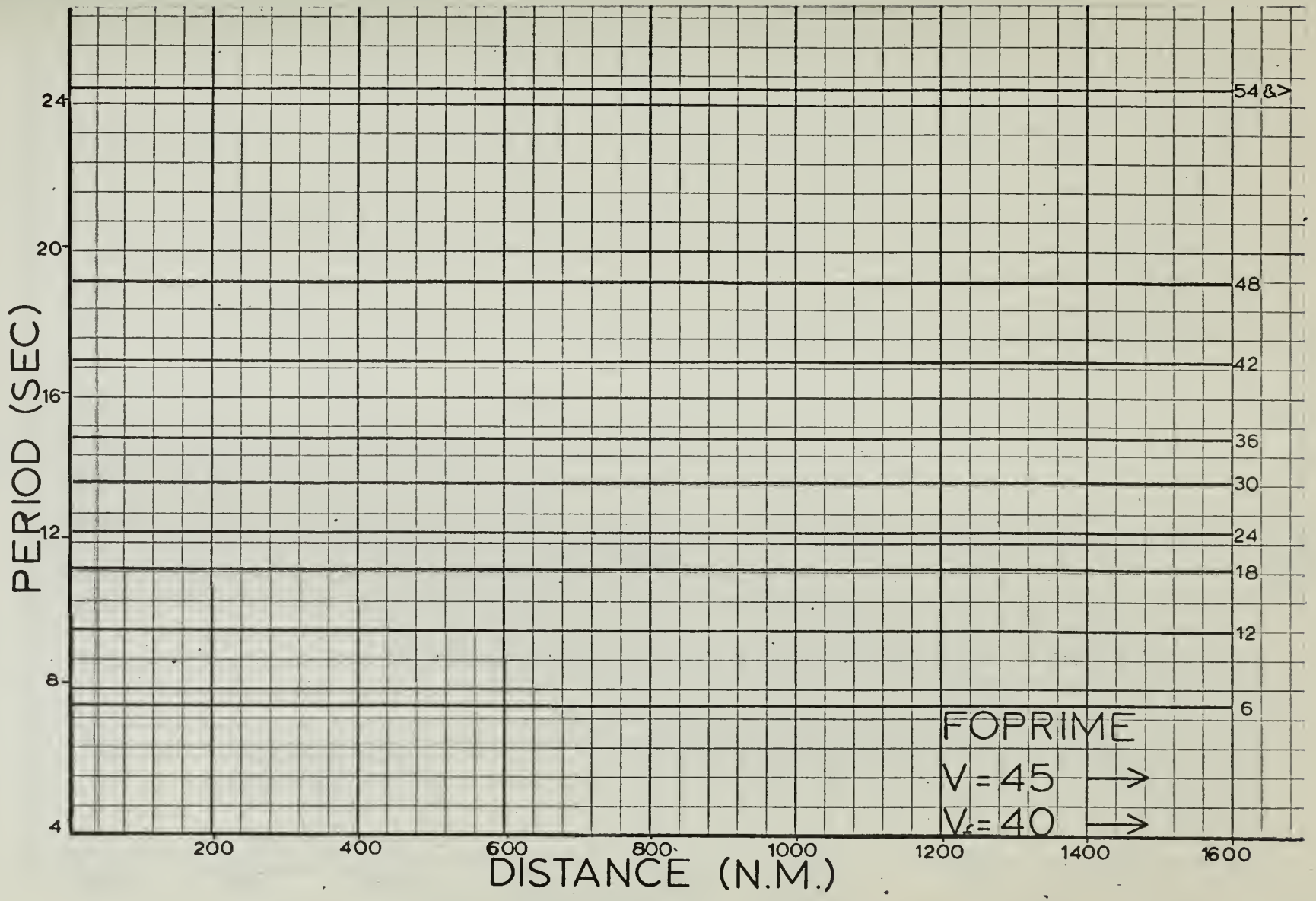

PERIOD (SEC)
24
20
16
12
8
4
150
300
450
600
750
900
1050
1200
DISTANCE (N.M.)
54 &>
48
42
36
30
24
18
12
6
FOPRIME
V = 45
Vf = 35



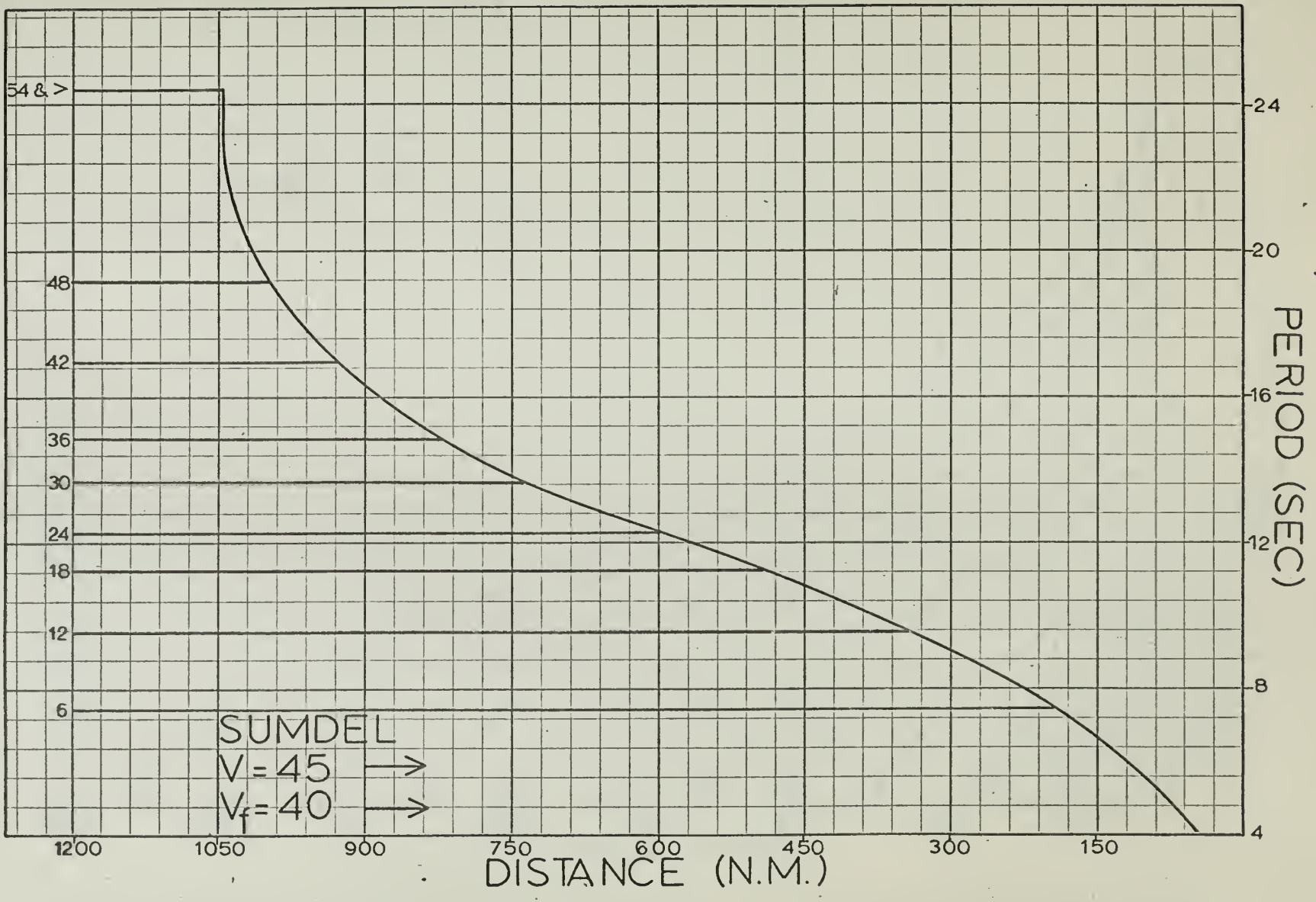

54 &>
48
42
36
30
24
18
12
6
SUMDEL
V = 45
Vf = 35
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)



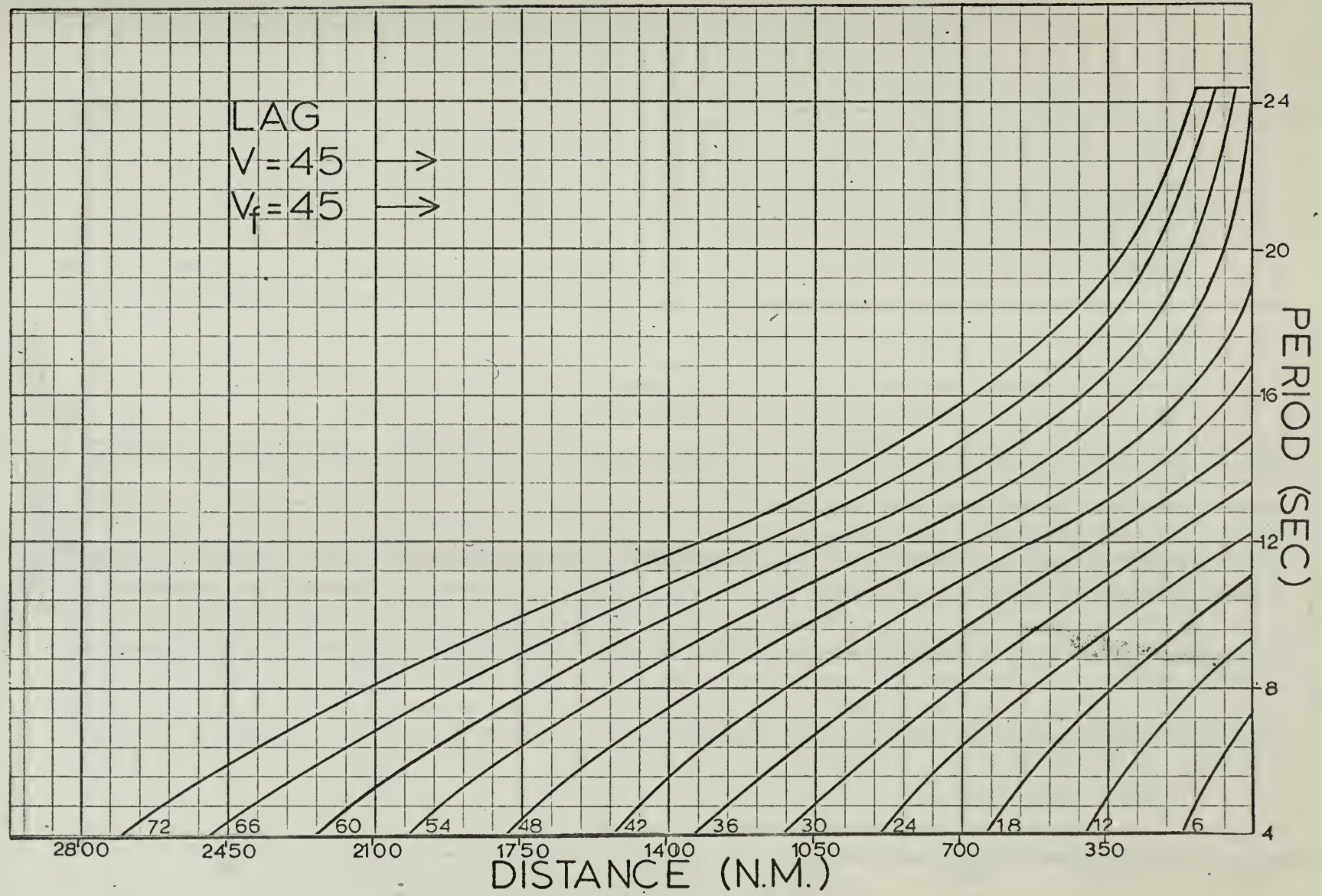

LAG
V = 45 →
V_f = 40 →
72
66
60
54
48
42
36
30
24
18
12
6
24
20
16
12
8
4
PERIOD (SEC)
2400
2100
1800
1500
1200
900
600
300
DISTANCE (N.M)

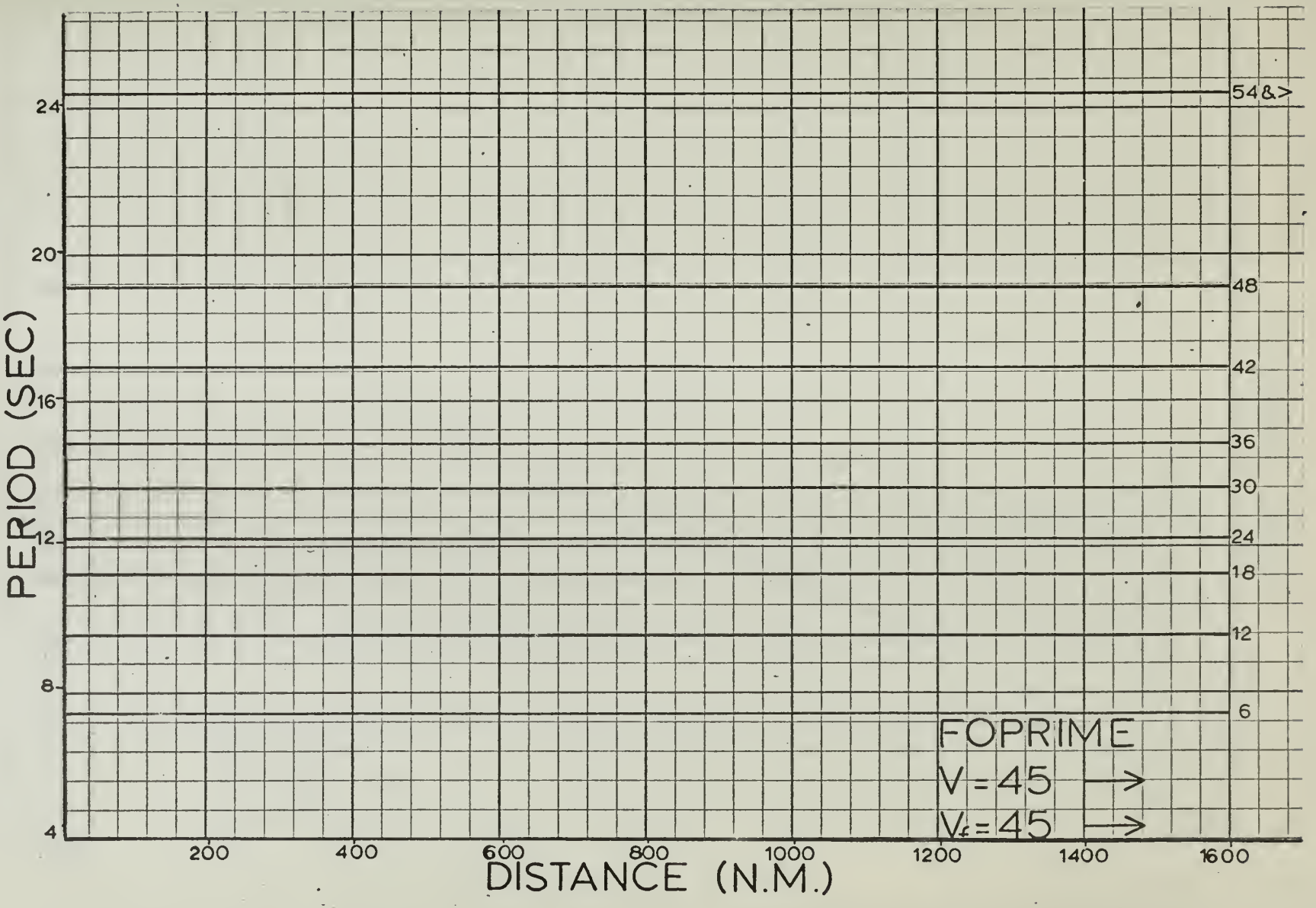

PERIOD (SEC)
24
20
16
12
8
4
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
54 &>
48
42
36
30
24
18
12
6
FOPRIME
V = 45 →
V_c = 40 →

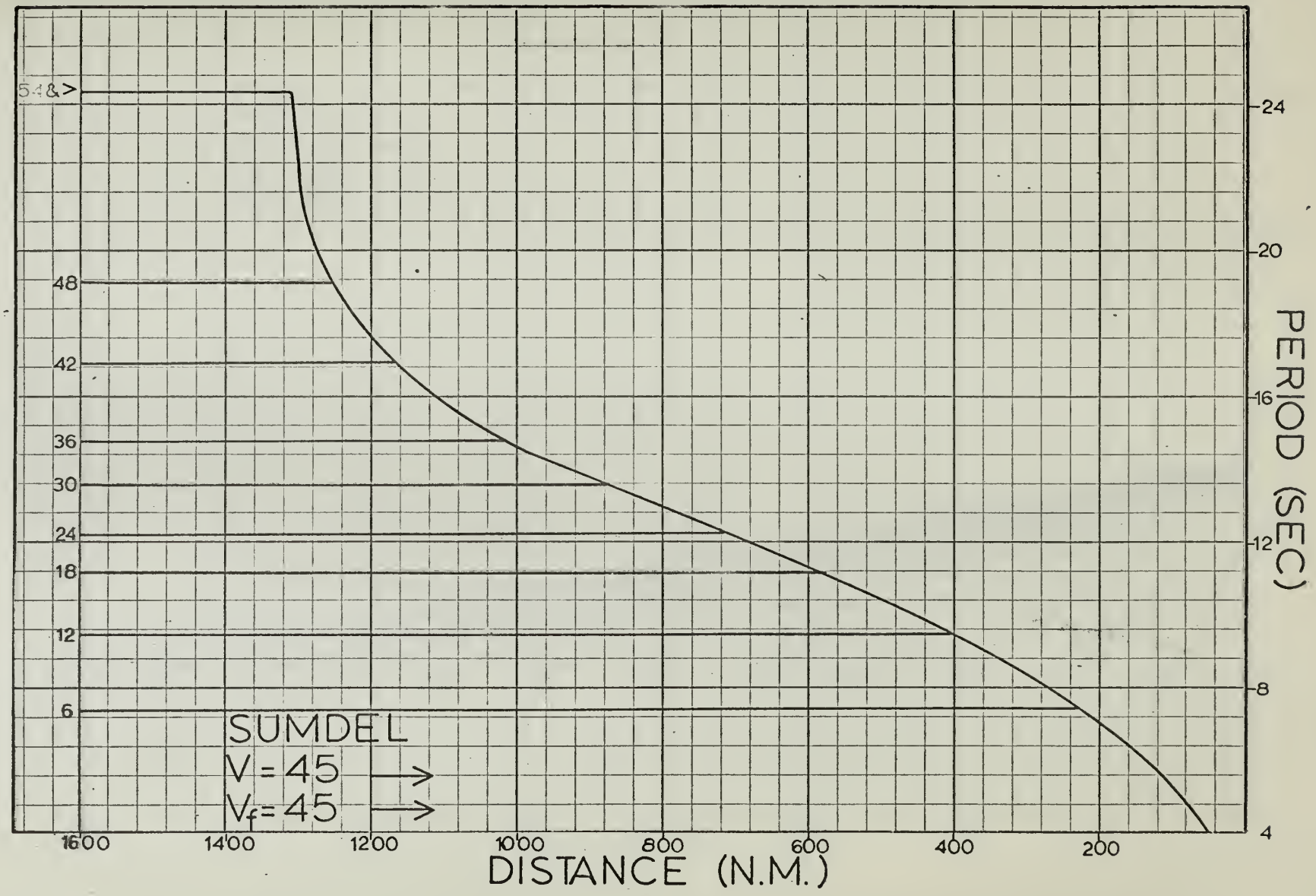


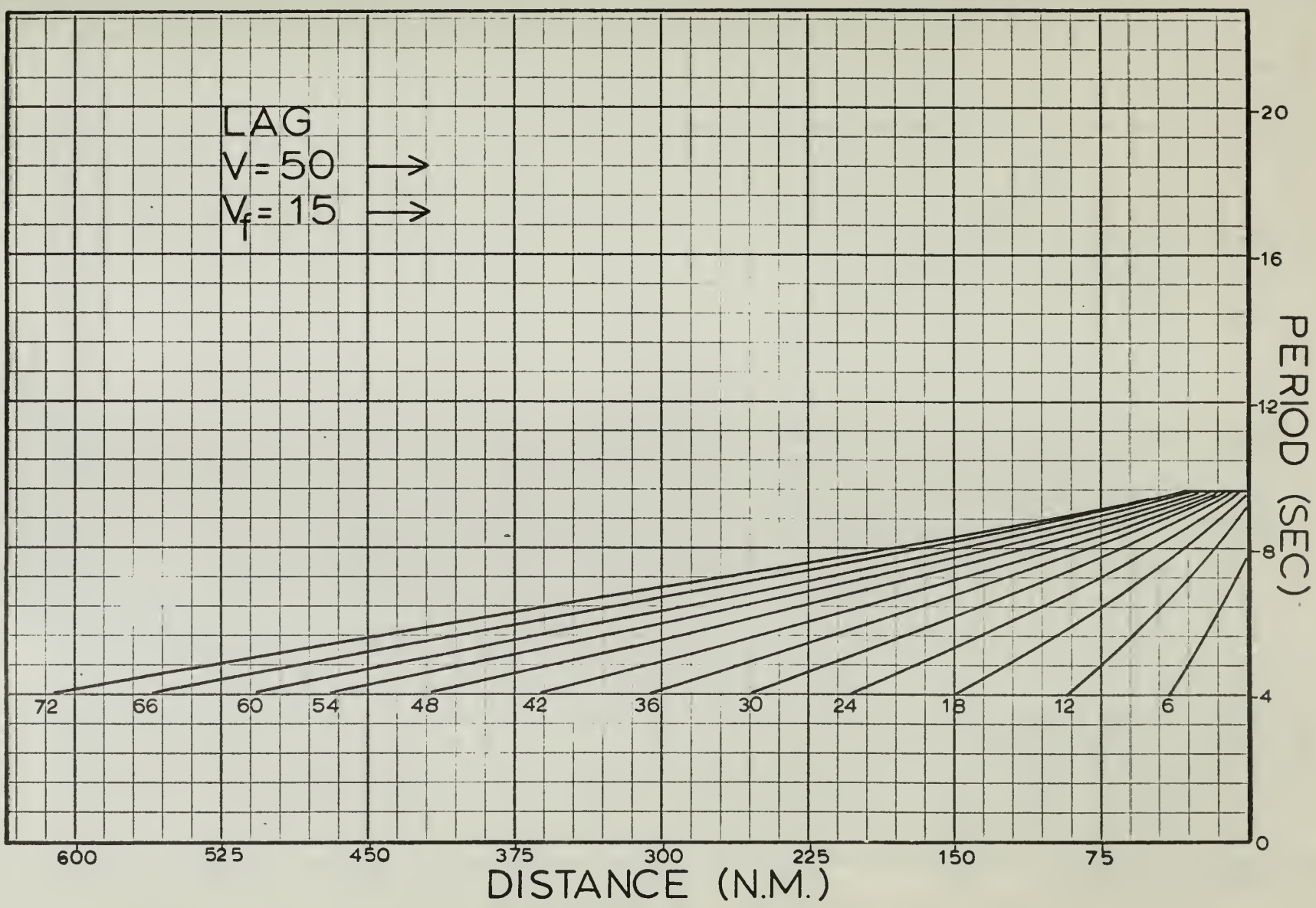

54 &>
48
42
36
30
24
18
12
6
SUMDEL
V = 45 →
Vf = 40 →
1200
1050
900
750
600
450
300
150
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

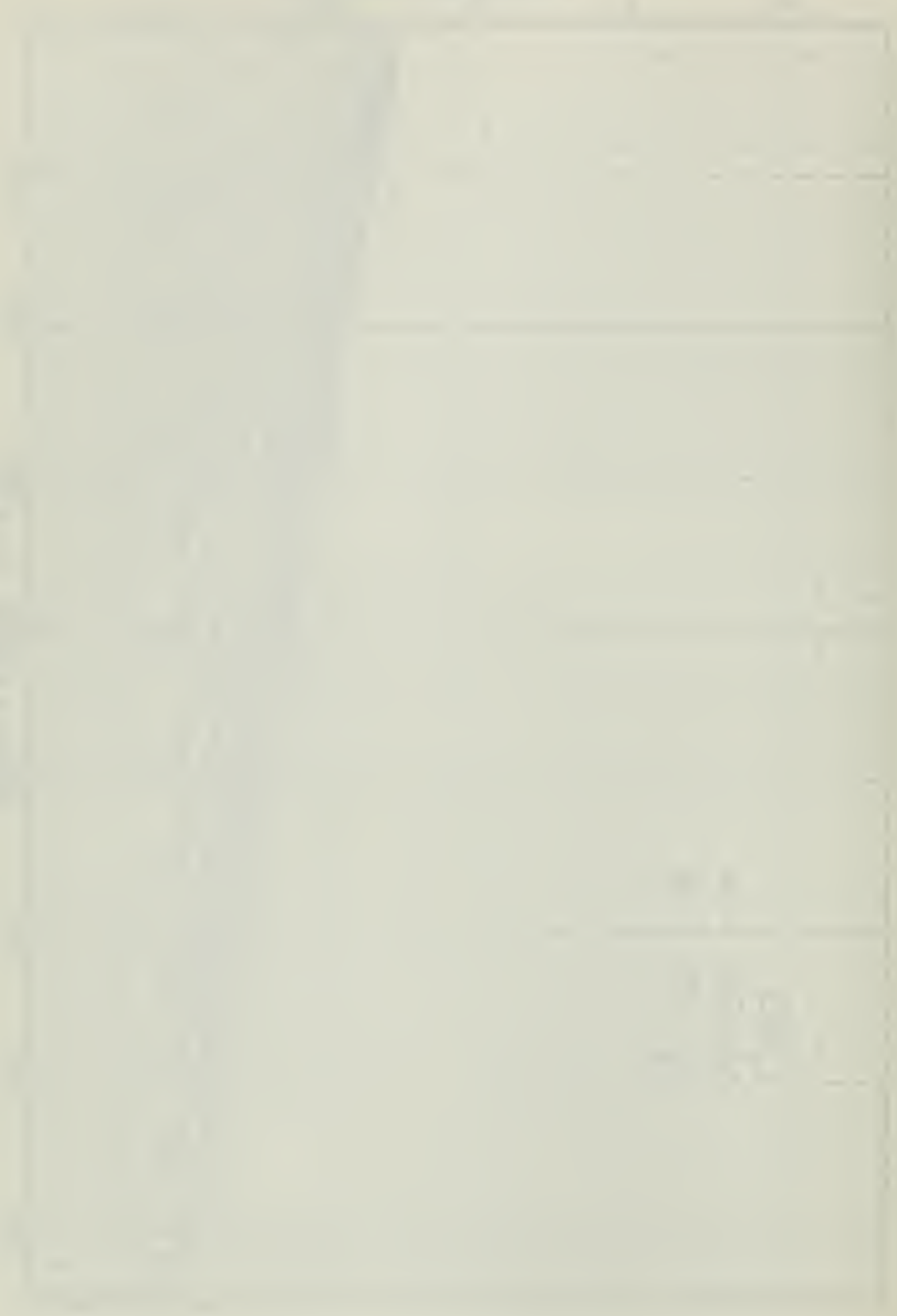


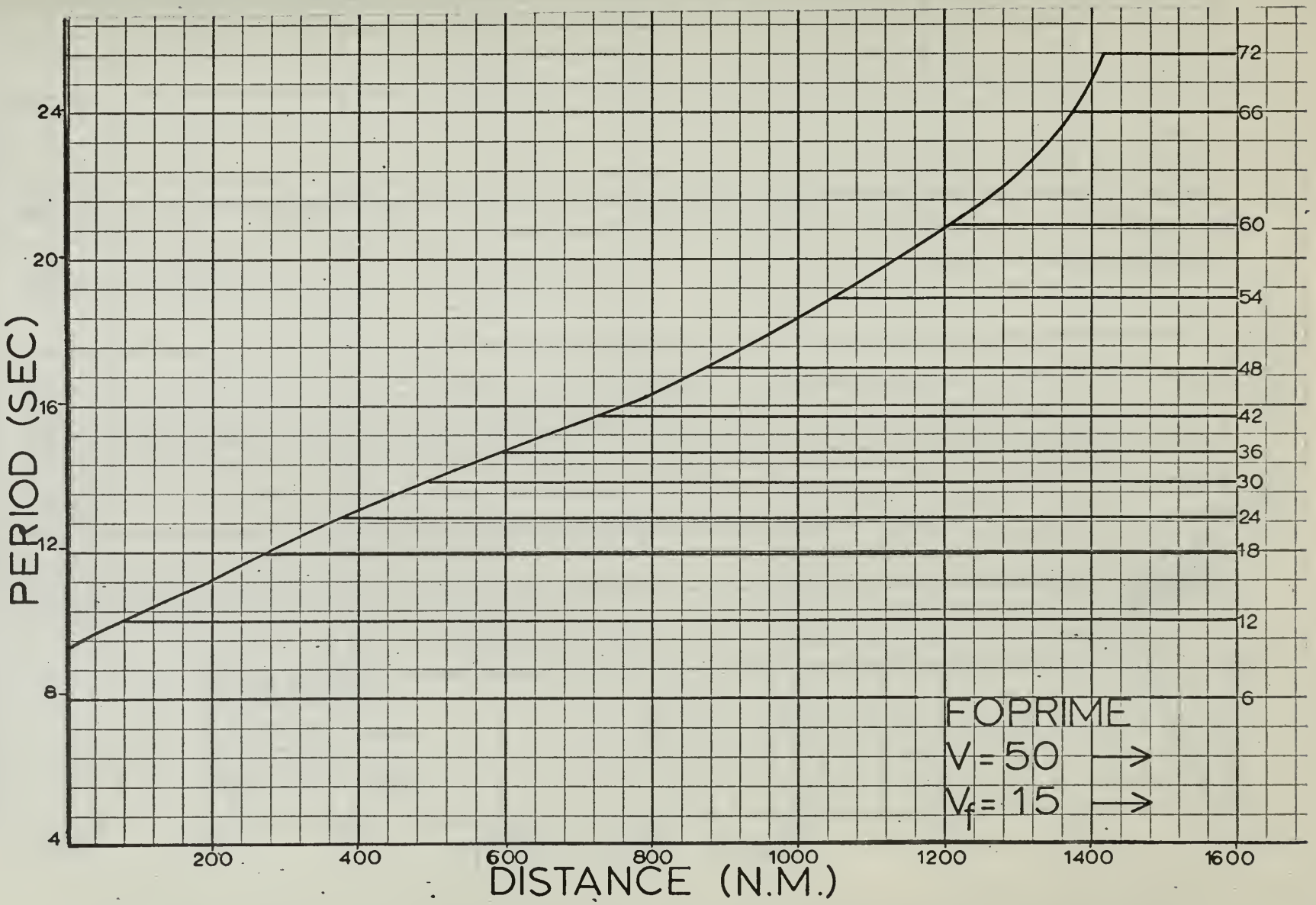

LAG
V = 45 →
V_f = 45 →
72
66
60
54
48
42
36
30
24
18
12
6
28'00
24'50
21'00
17'50
14'00
10'50
700
350
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)


PERIOD (SEC)
24
20
16
12
8
4
54 &>
48
42
36
30
24
18
12
6
FOPRIME
V = 45 →
Vf = 45 →
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

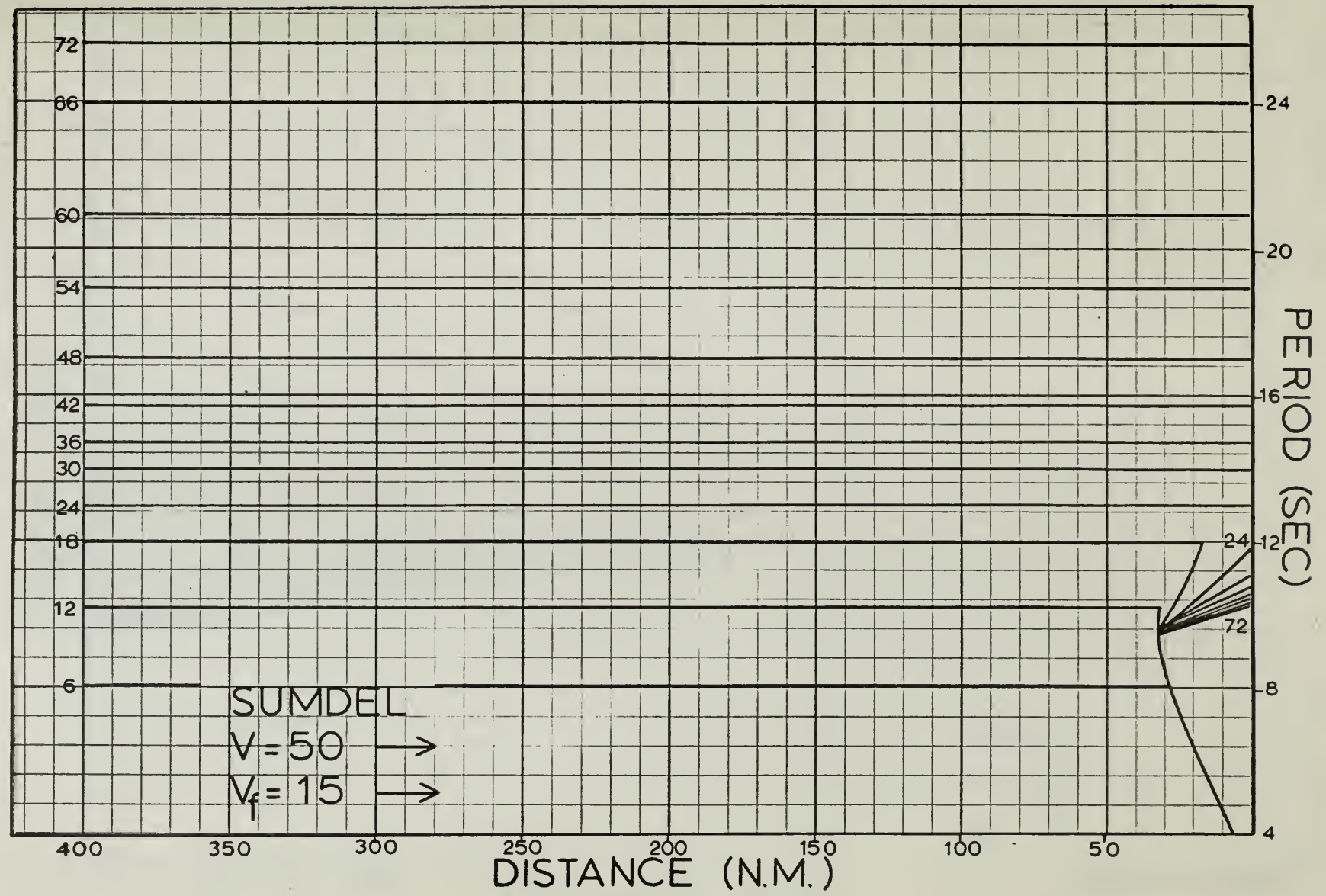

54 &>
48
42
36
30
24
18
12
6
SUMDEL
V = 45
Vf = 45
1600
1400
1200
1000
800
600
400
200
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)


LAG
V = 50 →
Vf = 15 →
72
66
60
54
48
42
36
30
24
18
12
6
600
525
450
375
300
225
150
75
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)

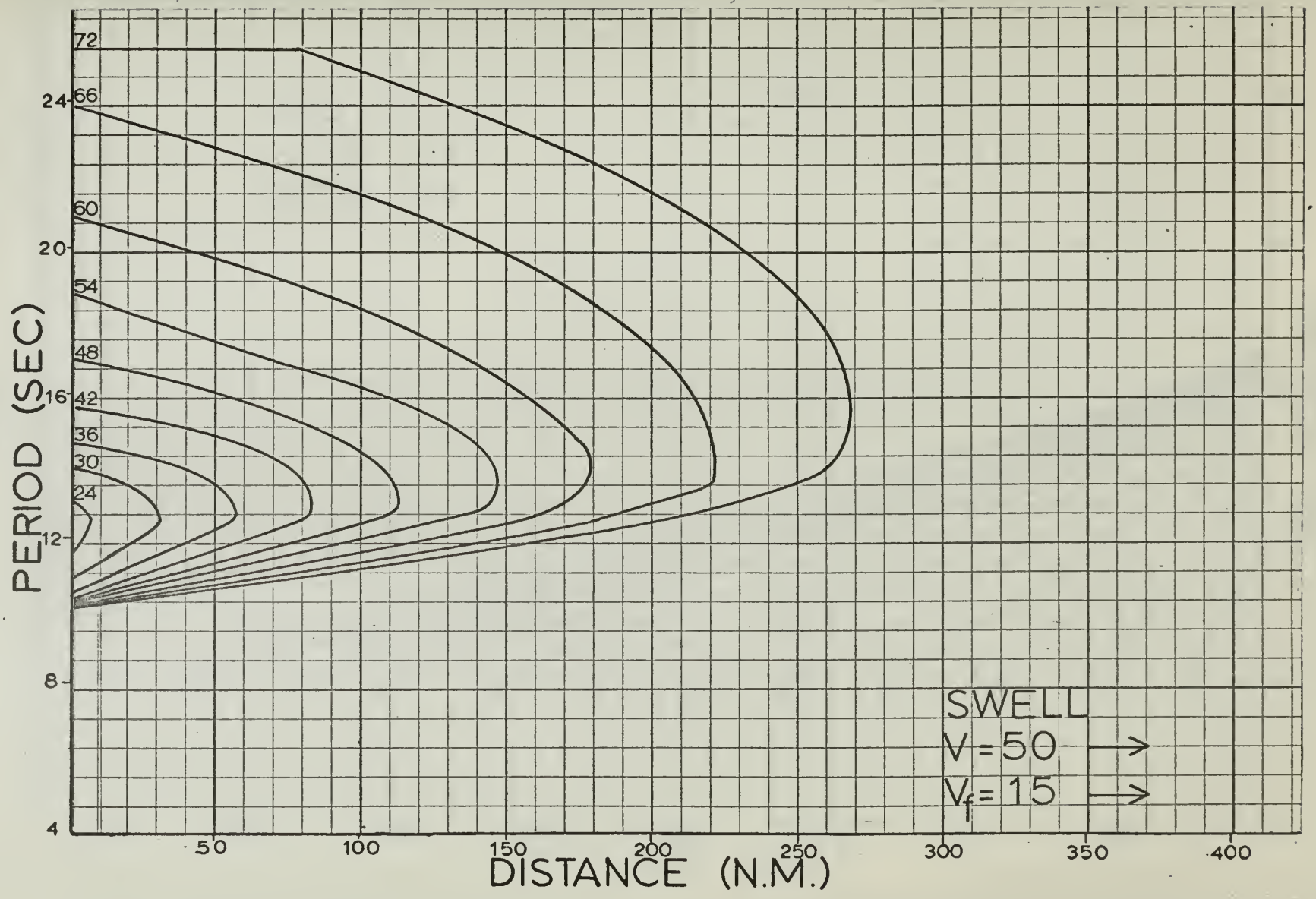



PERIOD (SEC)
24
20
16
12
8
4
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 50 →
Vf = 15 →

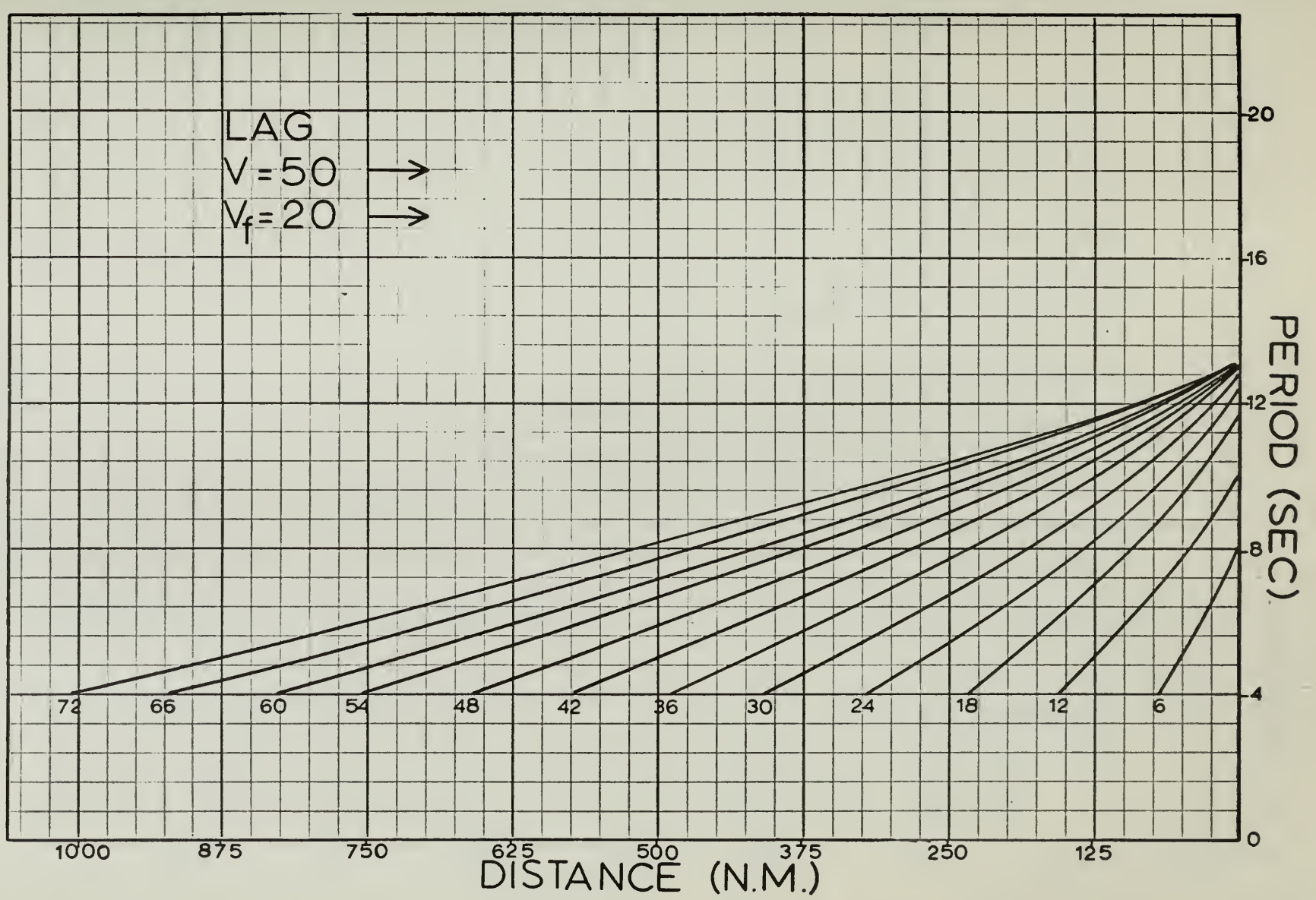



72
66
60
54
48
42
36
30
24
18
12
6
24
20
16
12
8
4
PERIOD (SEC)
24
72
SUMDEL
V = 50 →
V_f = 15 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)

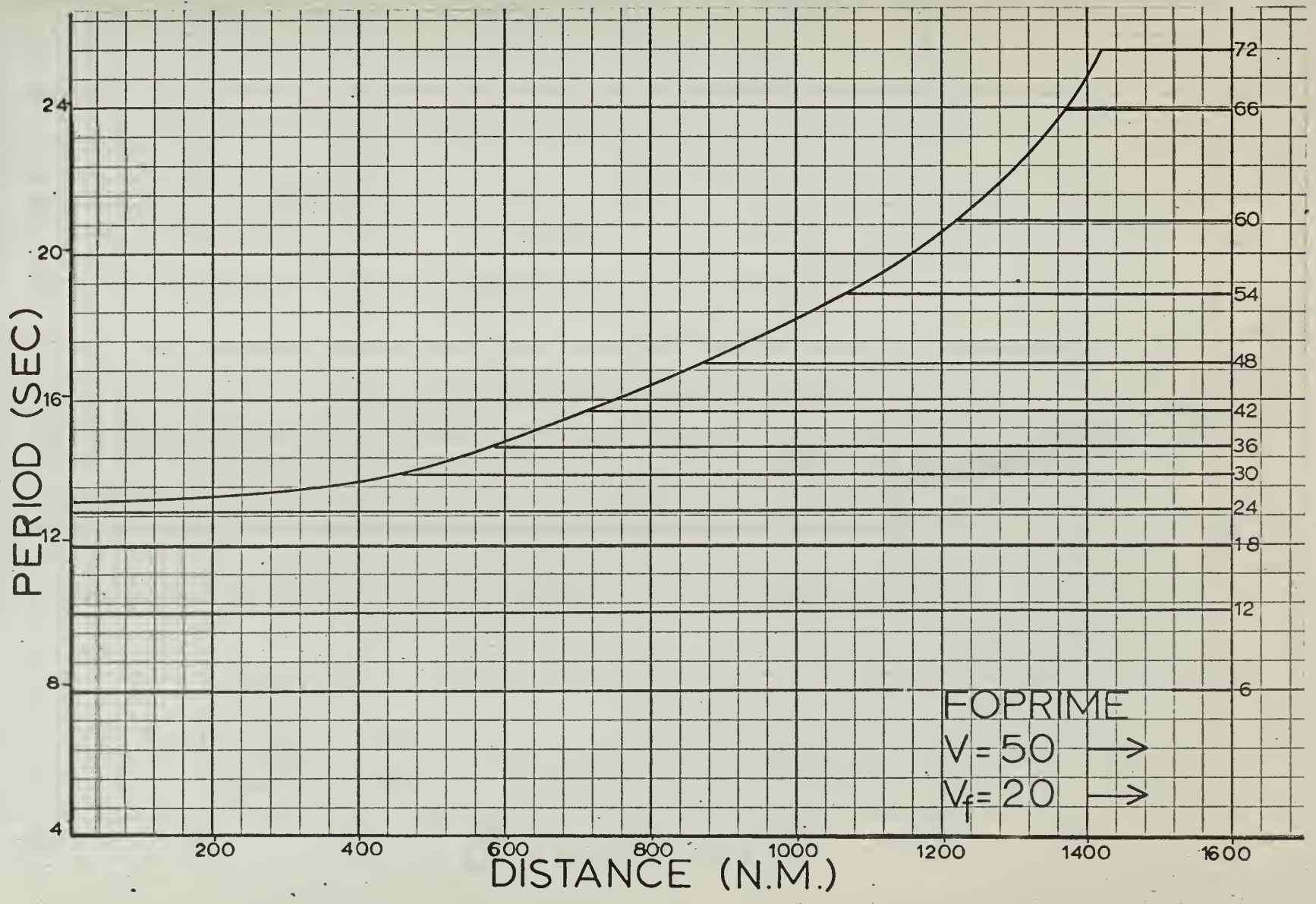



72
66
60
54
48
42
36
30
24
24
20
16
12
8
4
PERIOD (SEC)
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 50
Vf = 15

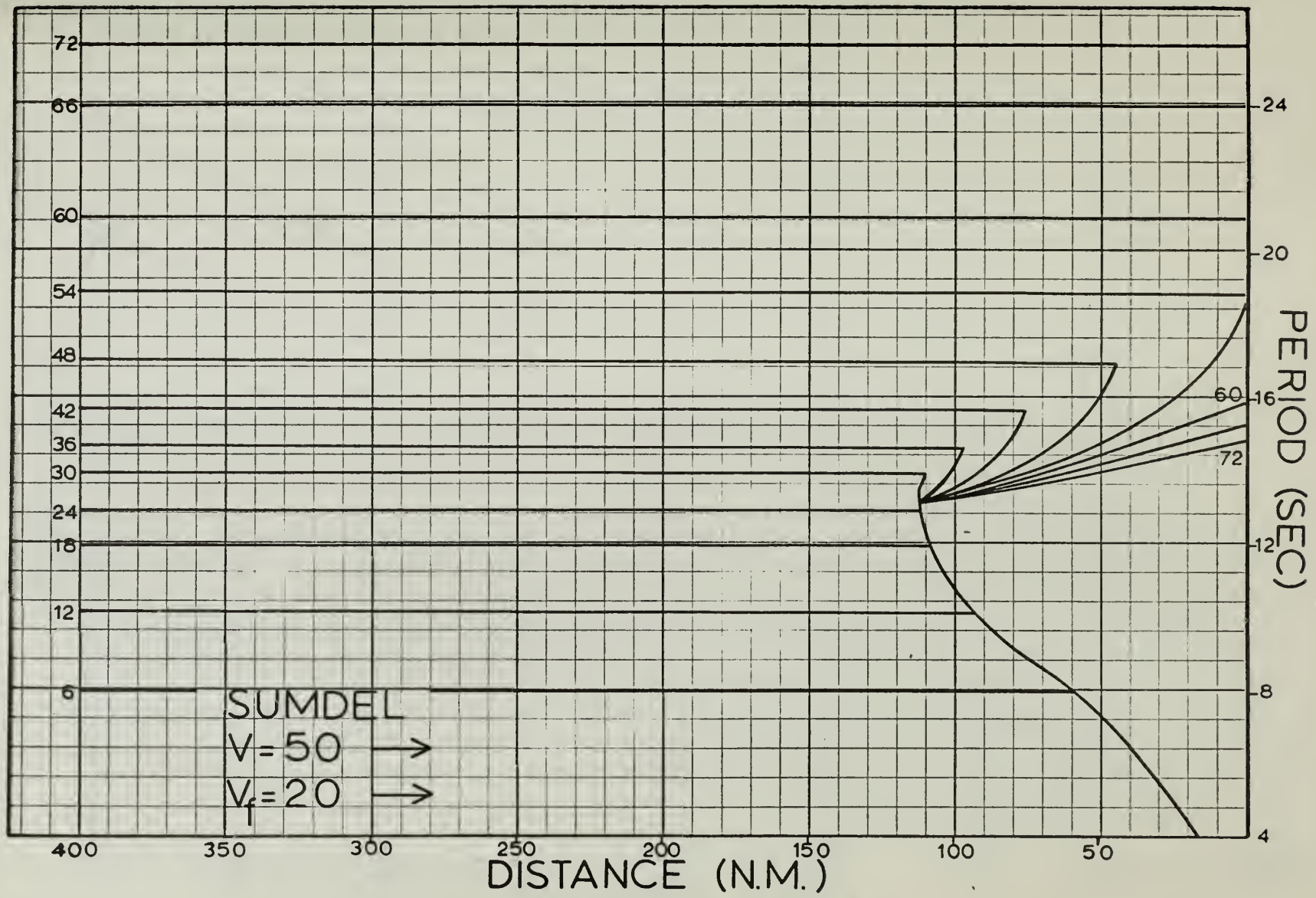



LAG
V = 50
V_f = 20
72
66
60
54
48
42
36
30
24
18
12
6
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
20
16
12
8
4
0
PERIOD (SEC)




PERIOD (SEC)
4
8
12
16
20
24
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 50 →
Vf = 20 →

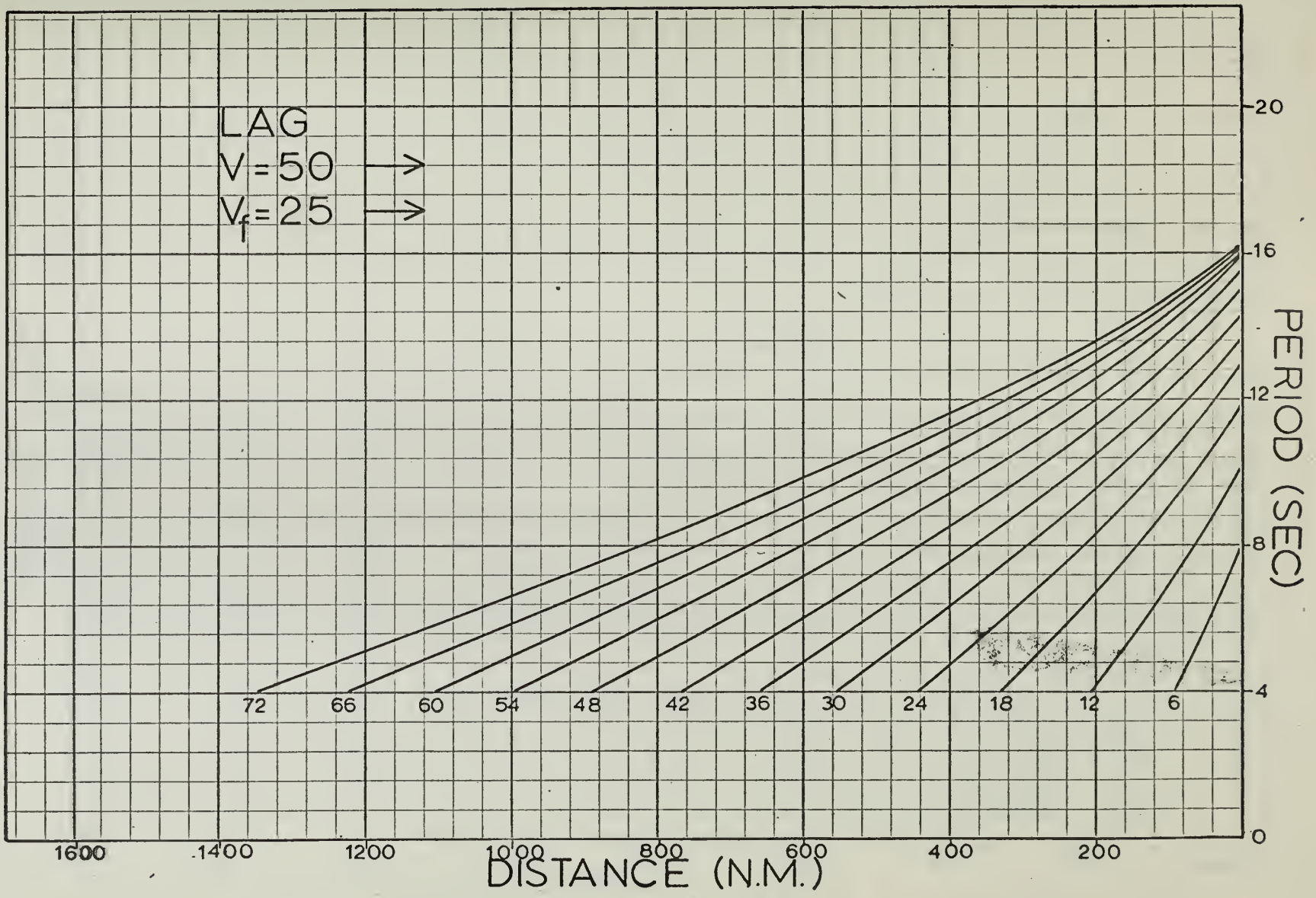



72
66
60
54
48
42
36
30
24
18
12
6
24
20
16
12
8
4
60
72
PERIOD (SEC)
SUMDEL
V = 50 →
Vf = 20 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)

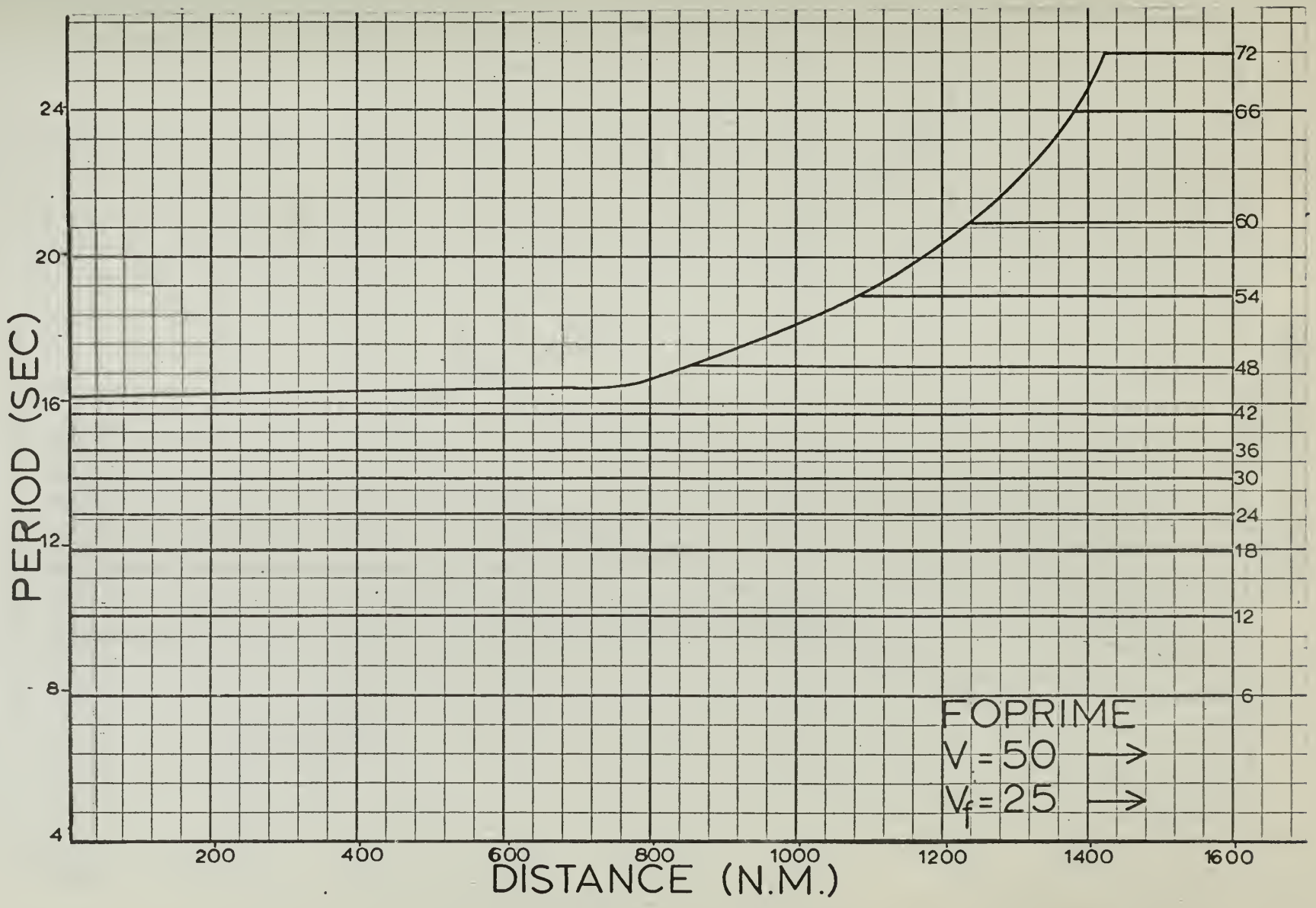


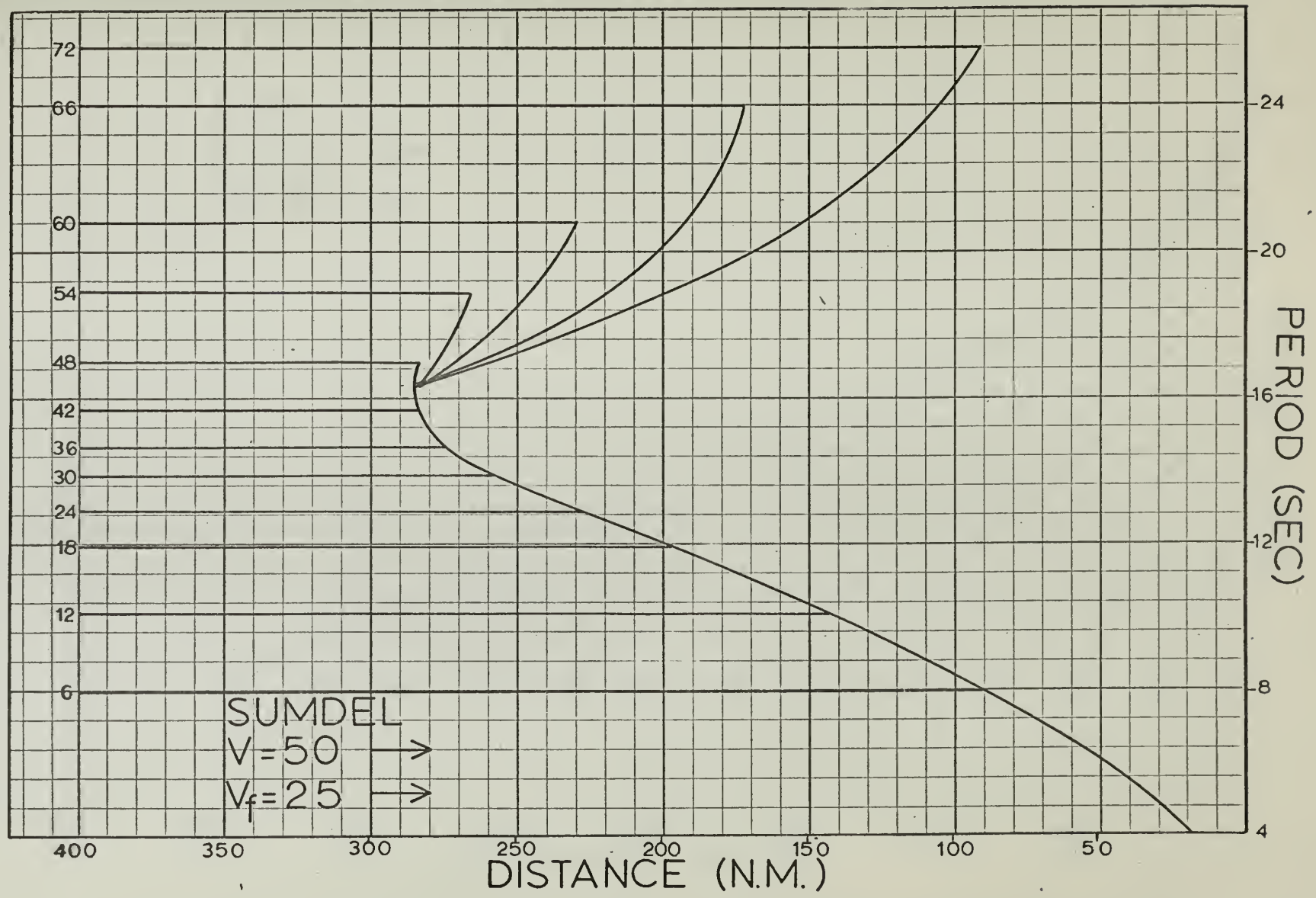

72
66
60
24
20
16
12
8
4
PERIOD (SEC)
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 50 →
Vf = 20 →



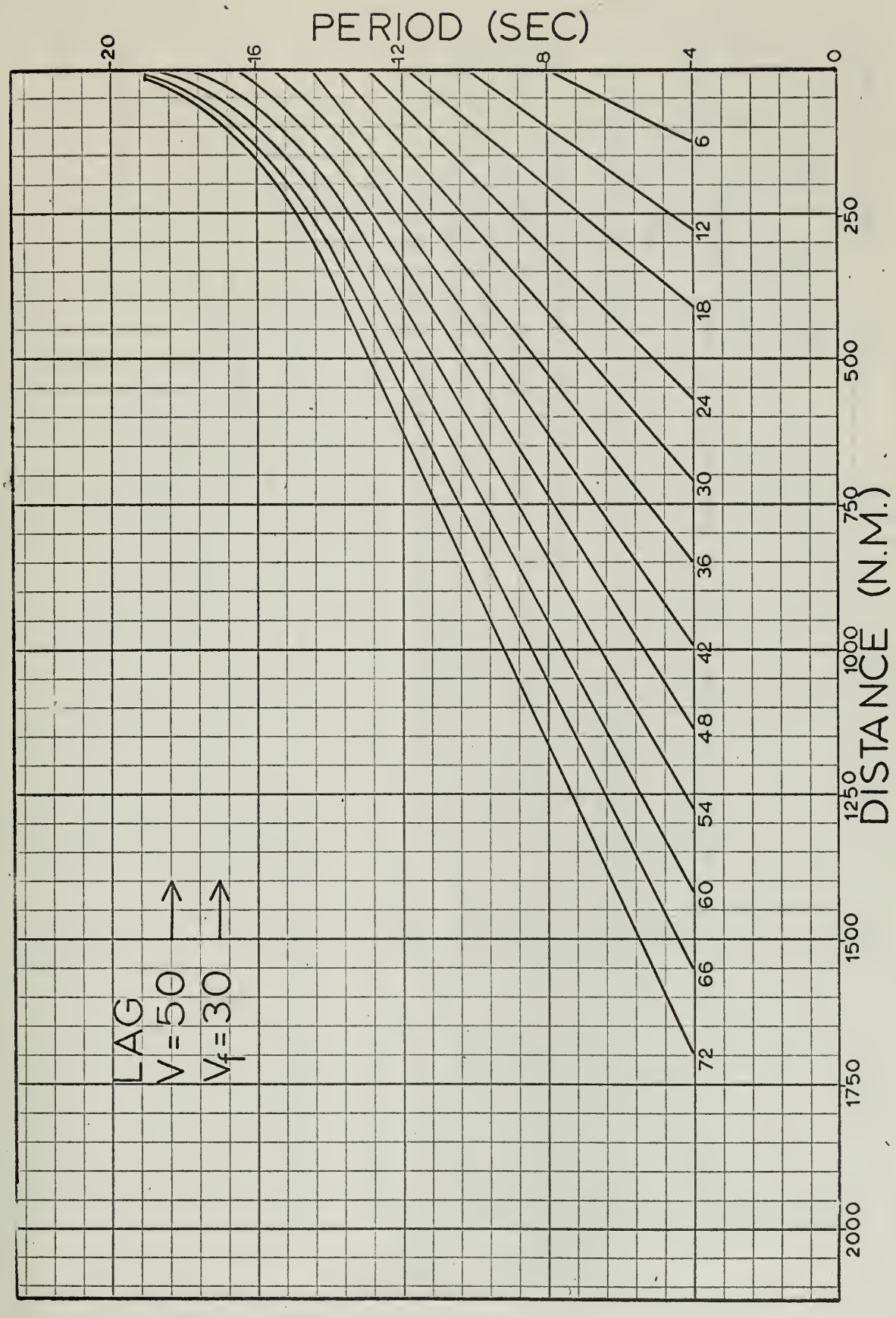

LAG
V = 50 →
Vf = 25 →
72
66
60
54
48
42
36
30
24
18
12
6
20
16
12
8
4
0
PERIOD (SEC)
1600
1400
1200
1000
800
600
400
200
DISTANCE (N.M.)



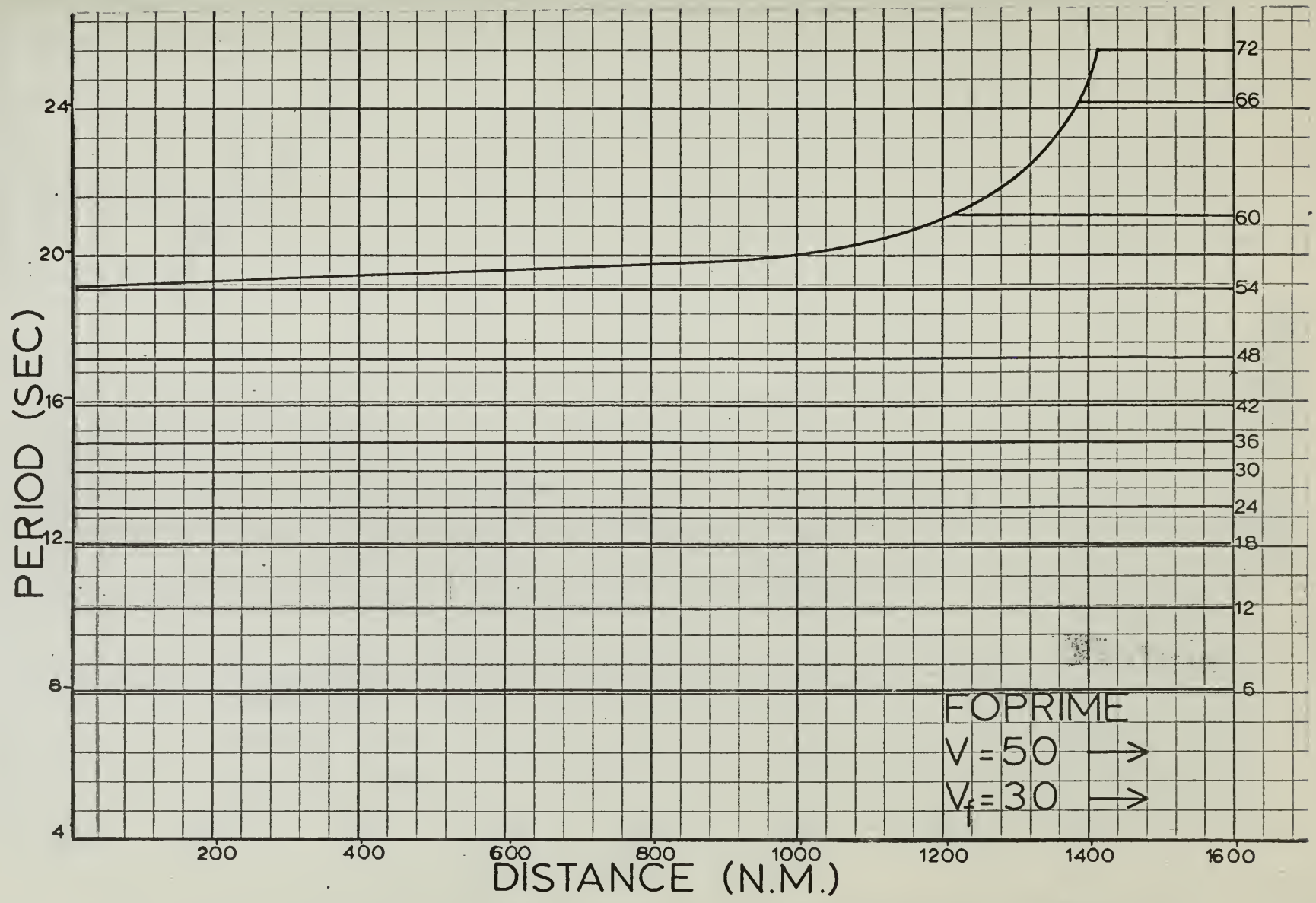

PERIOD (SEC)
24
20
16
12
8
4
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 50
Vf = 25


72
66
60
54
48
42
36
30
24
18
12
6
24
20
16
12
8
4
PERIOD (SEC)
SUMDEL
V=50 →
Vf=25 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)

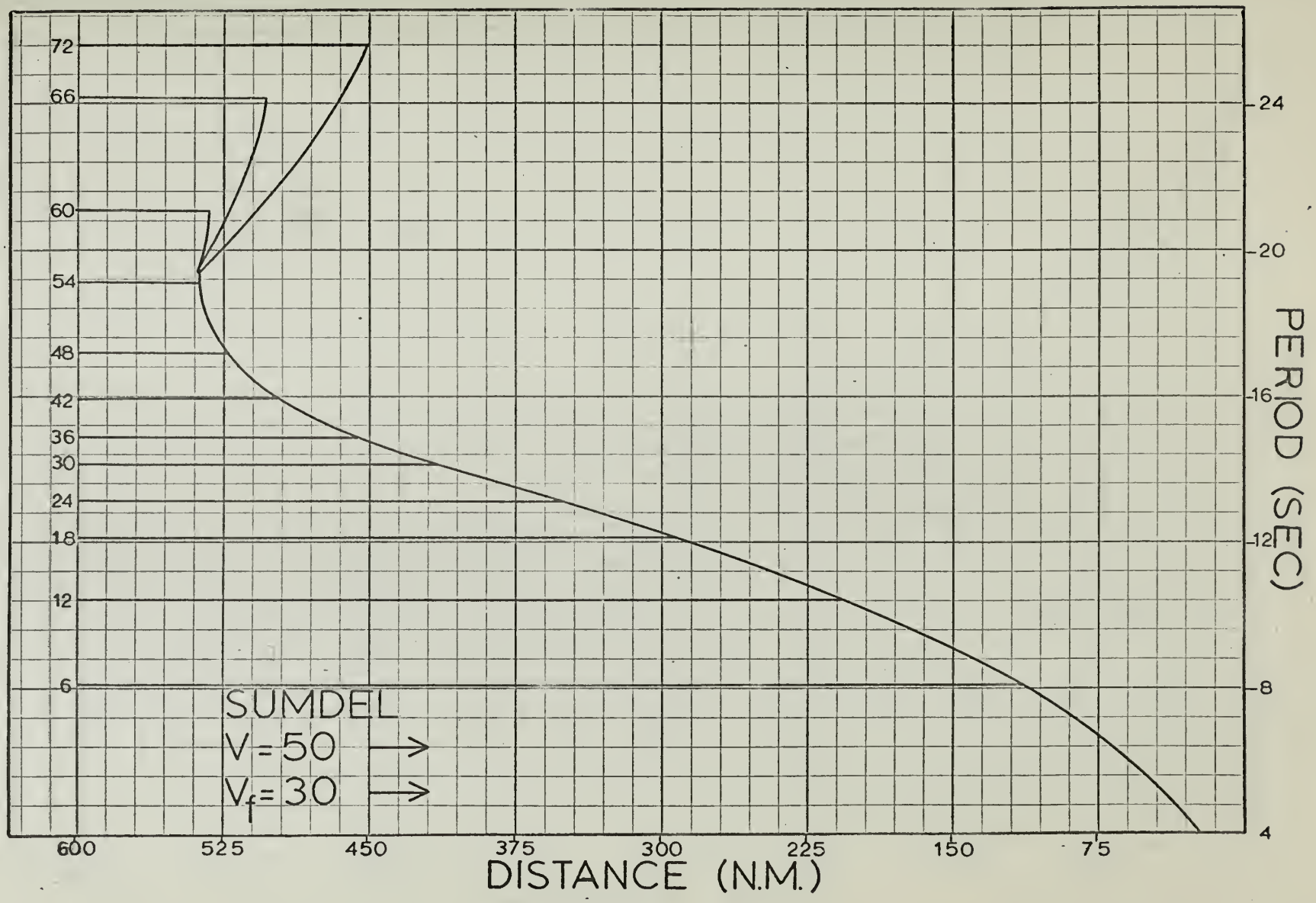



PERIOD (SEC)
20
16
12
8
4
0
DISTANCE (N.M.)
250
500
750
1000
1250
1500
1750
2000
LAG
V=50
Vf=30
6
12
18
24
30
36
42
48
54
60
66
72

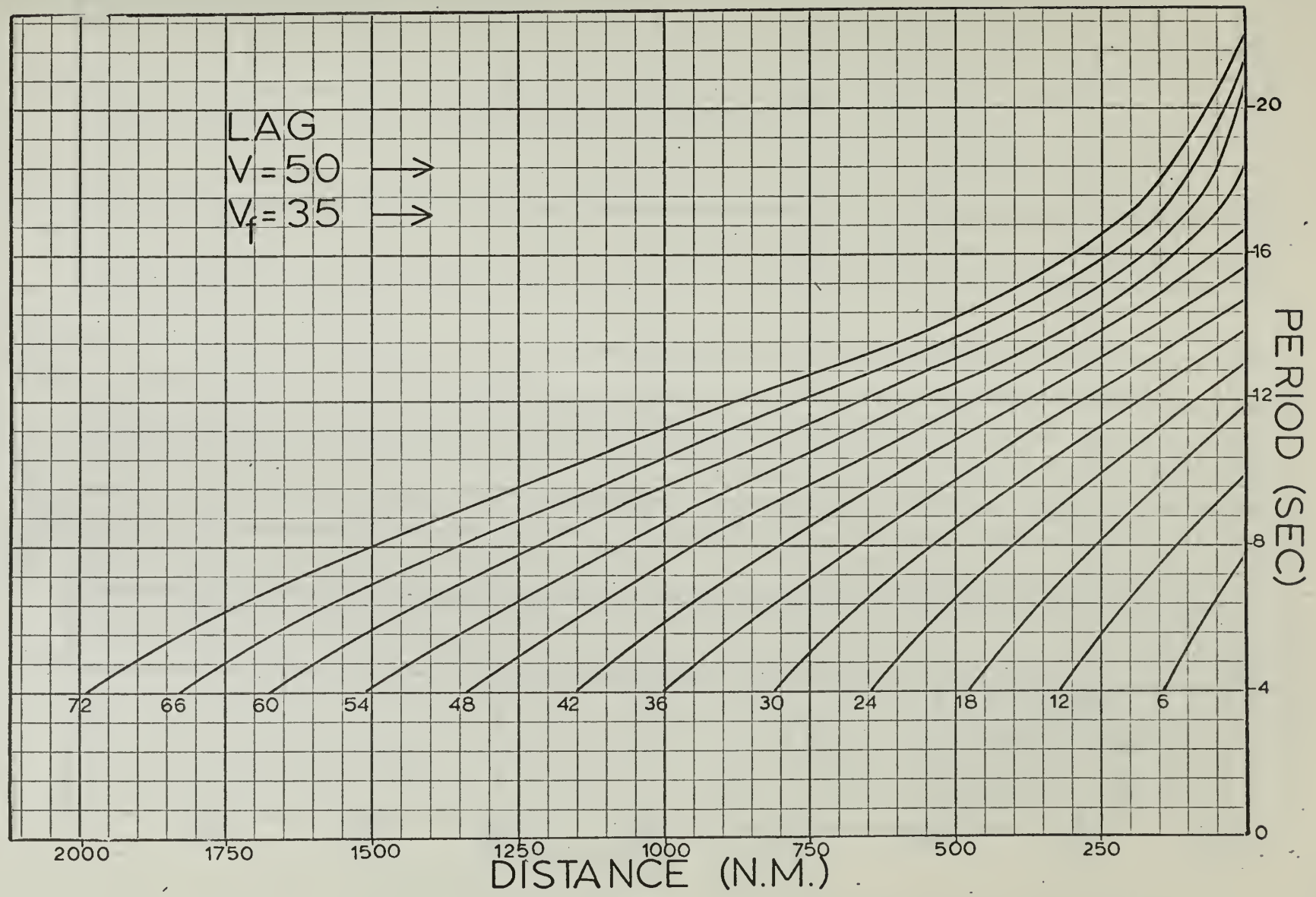



PERIOD (SEC)
4
8
12
16
20
24
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 50 →
Vf = 30 →

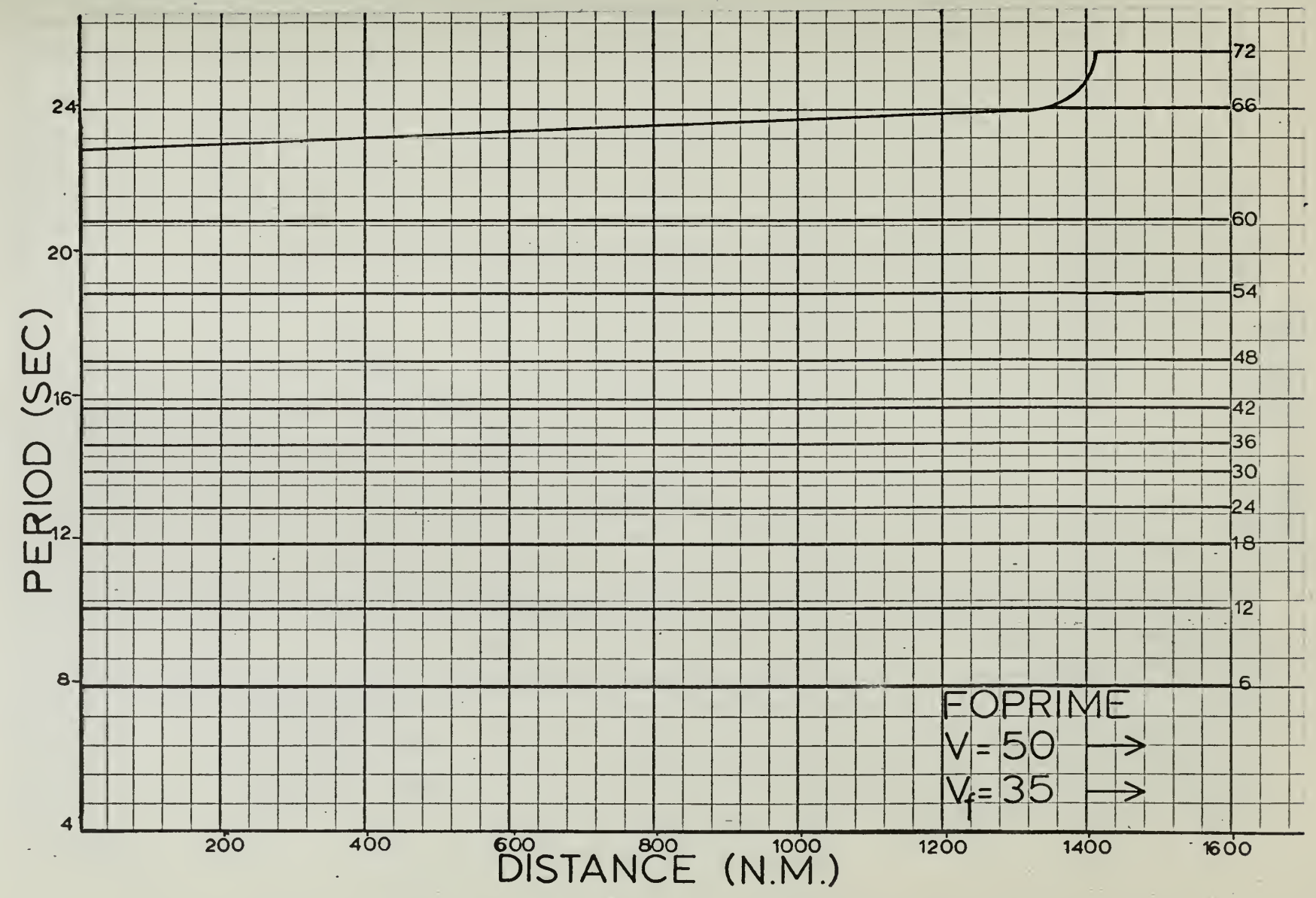



72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 50 →
V_f = 30 →
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

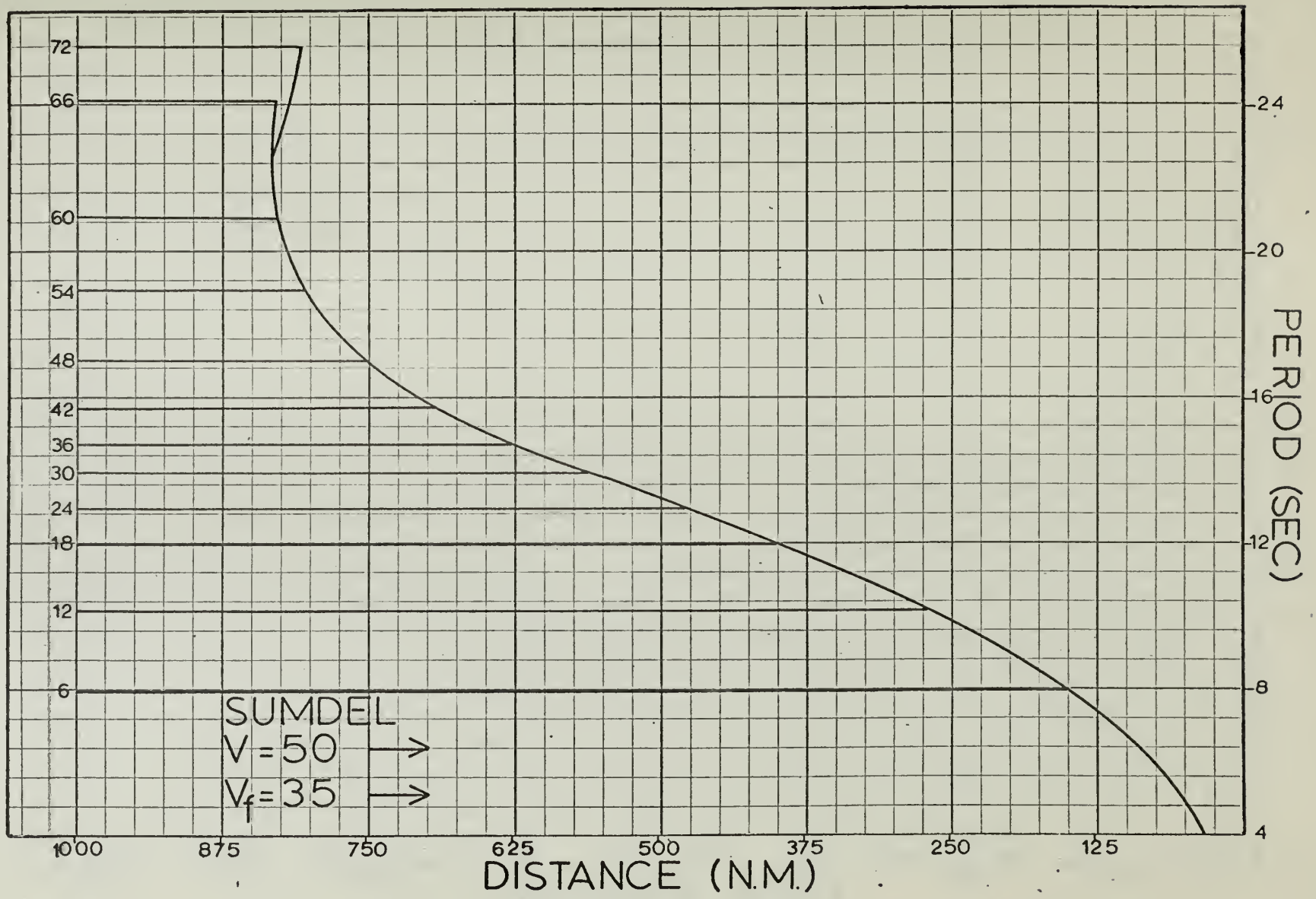



LAG
V = 50 →
V_f = 35 →
72
66
60
54
48
42
36
30
24
18
12
6
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

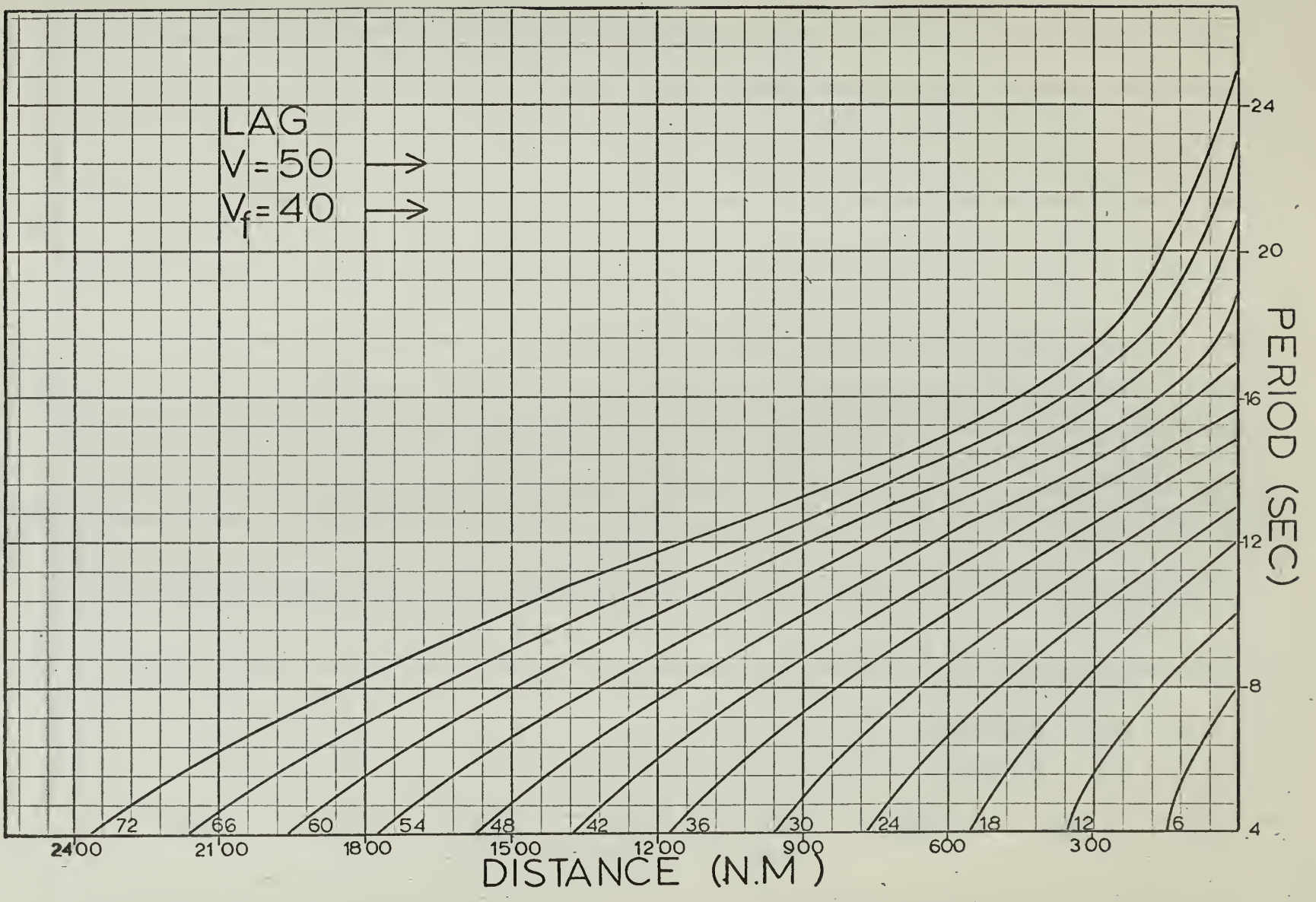


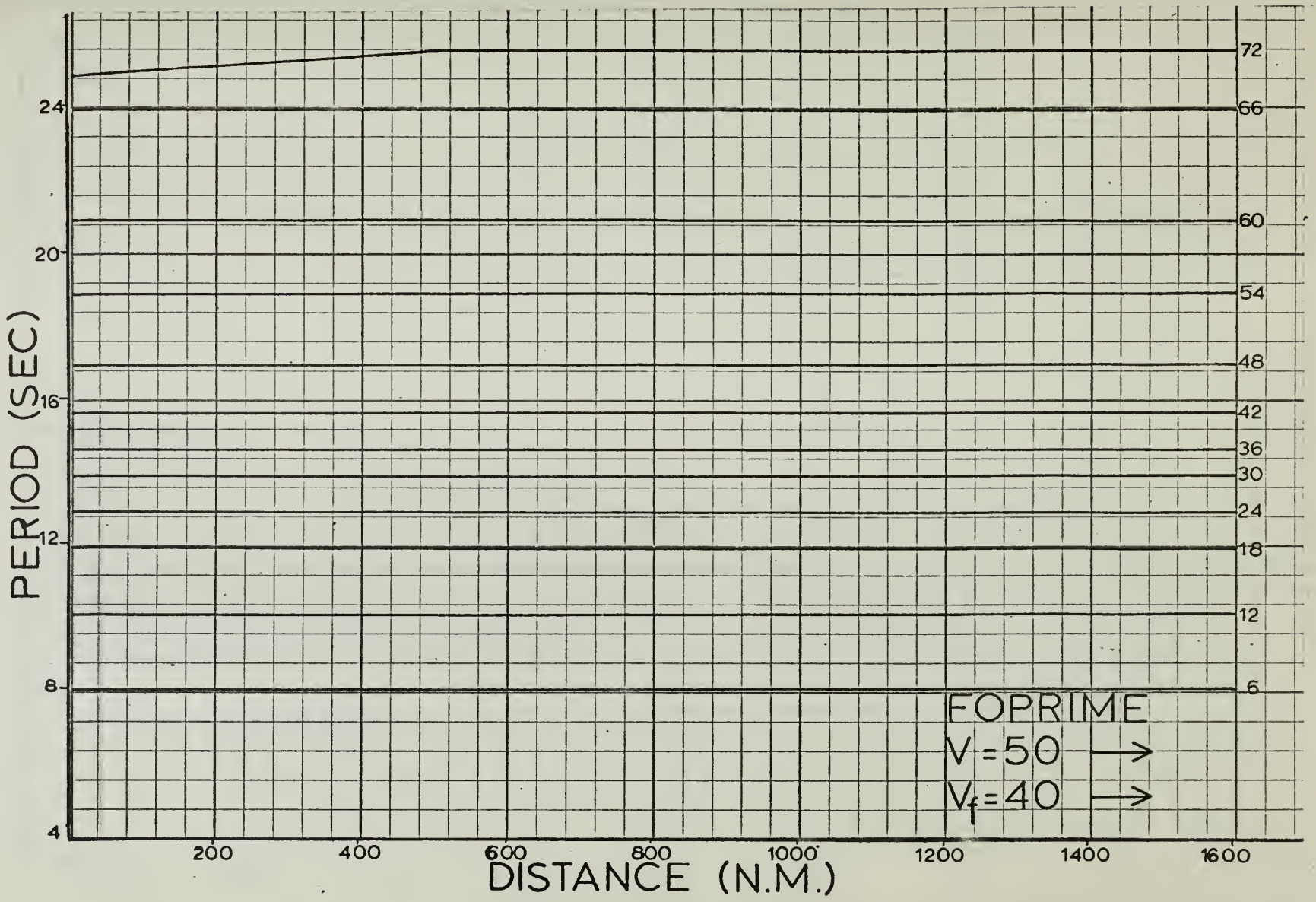

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 50
Vf = 35
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)



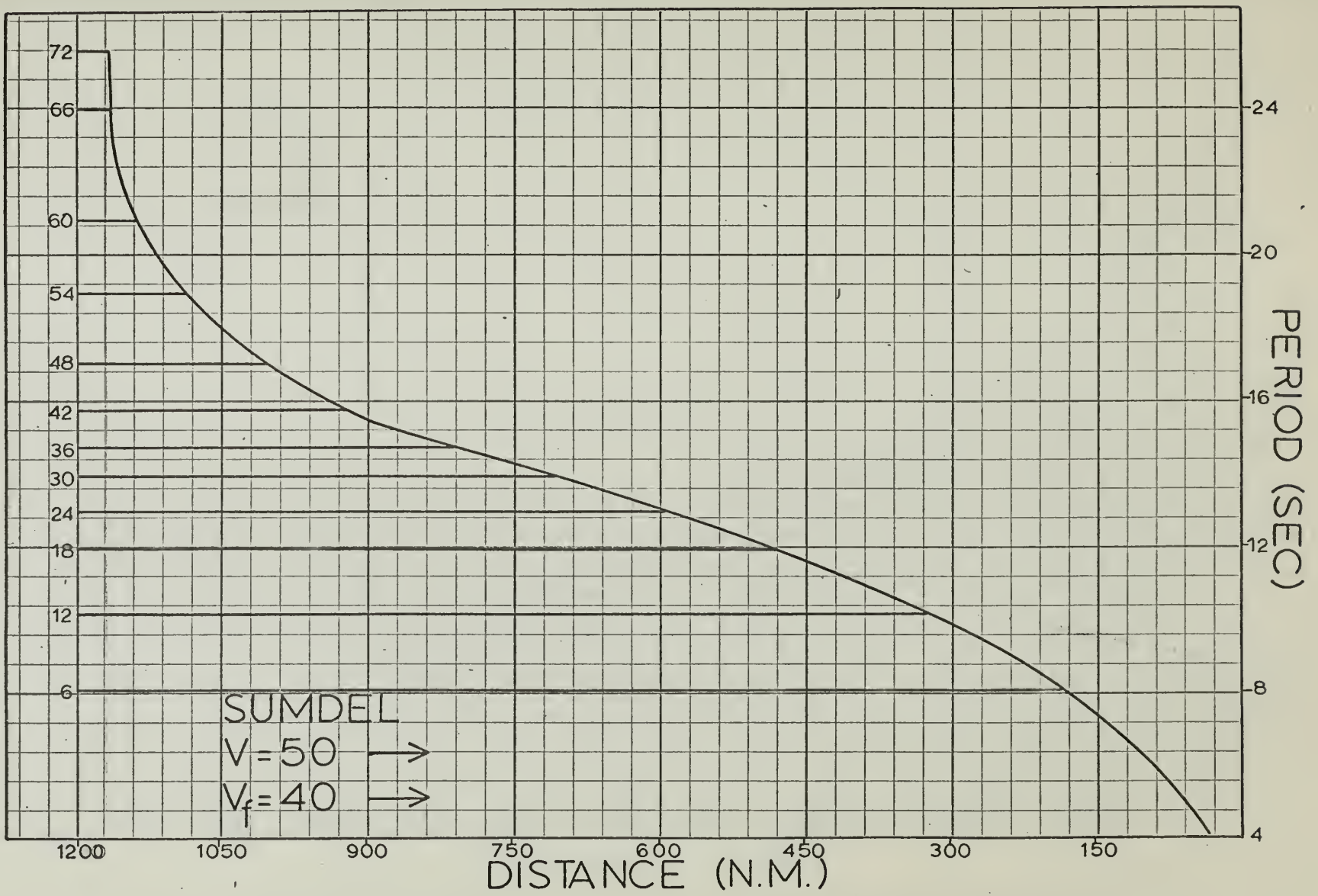

72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 50 →
Vf = 35 →
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

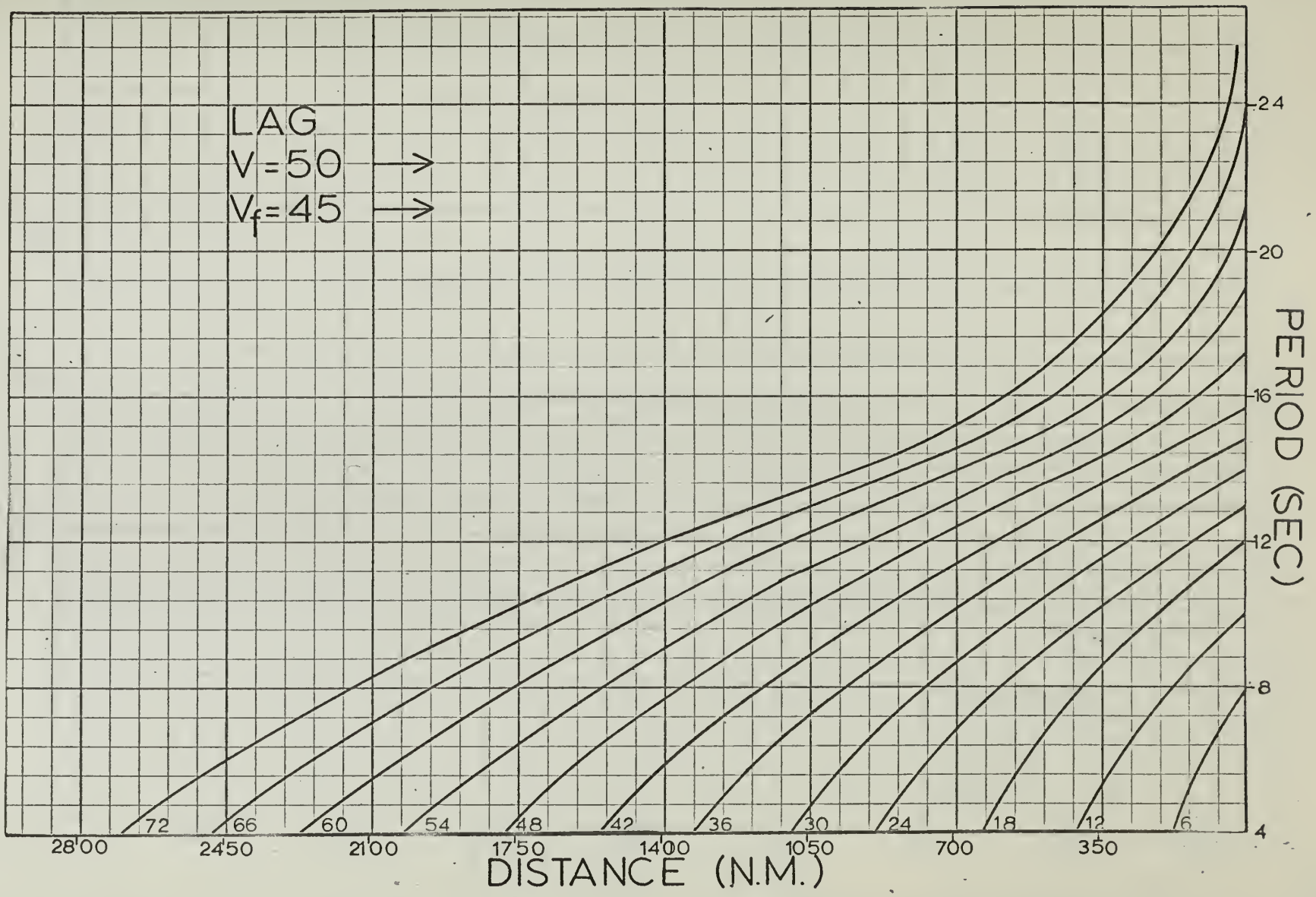



LAG
V = 50 →
V_f = 40 →
72
66
60
54
48
42
36
30
24
18
12
6
2400
2100
1800
1500
1200
900
600
300
DISTANCE (N.M)
4
8
12
16
20
24
PERIOD (SEC)

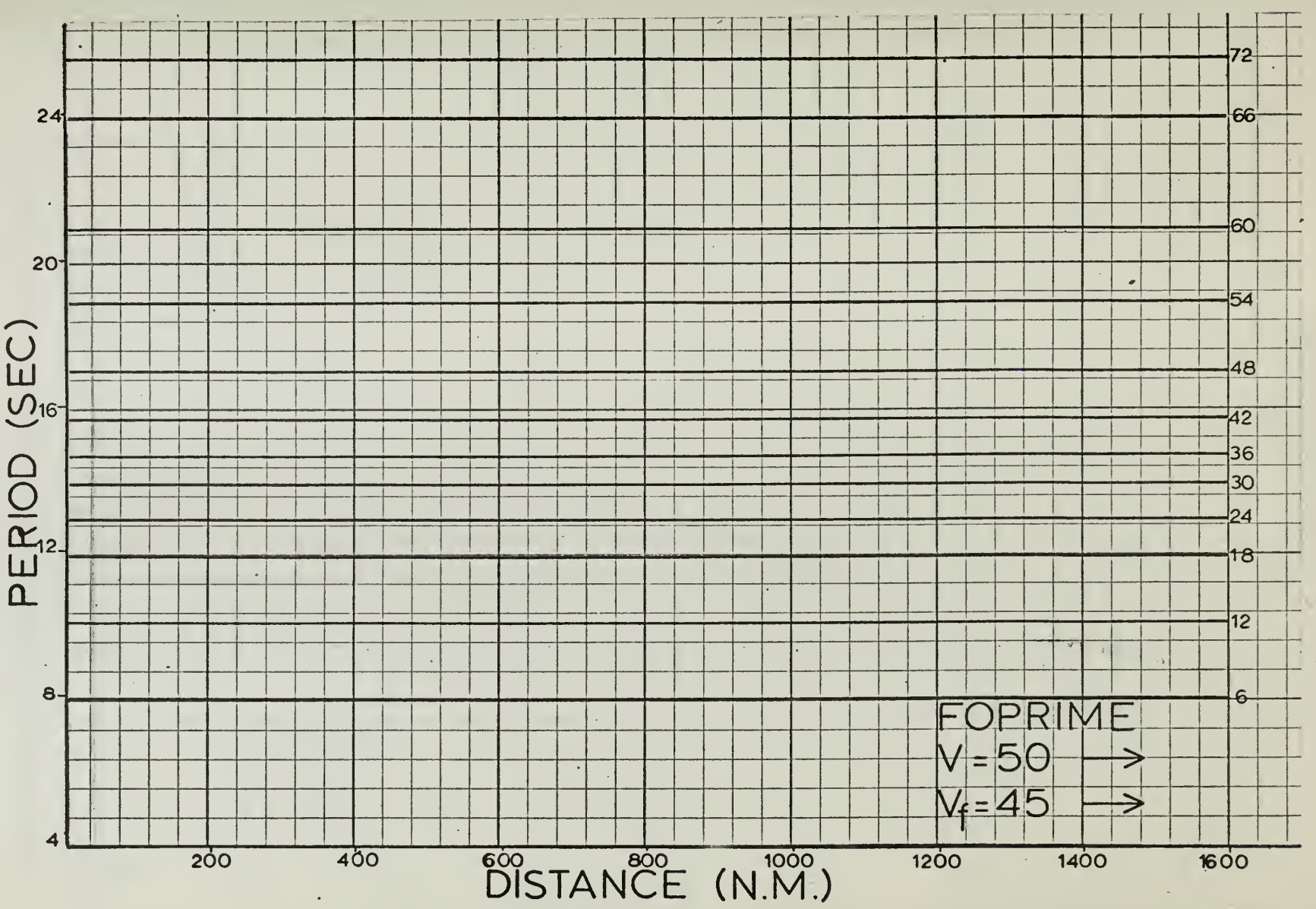

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
FOPRIME
V = 50 →
V_f = 40 →

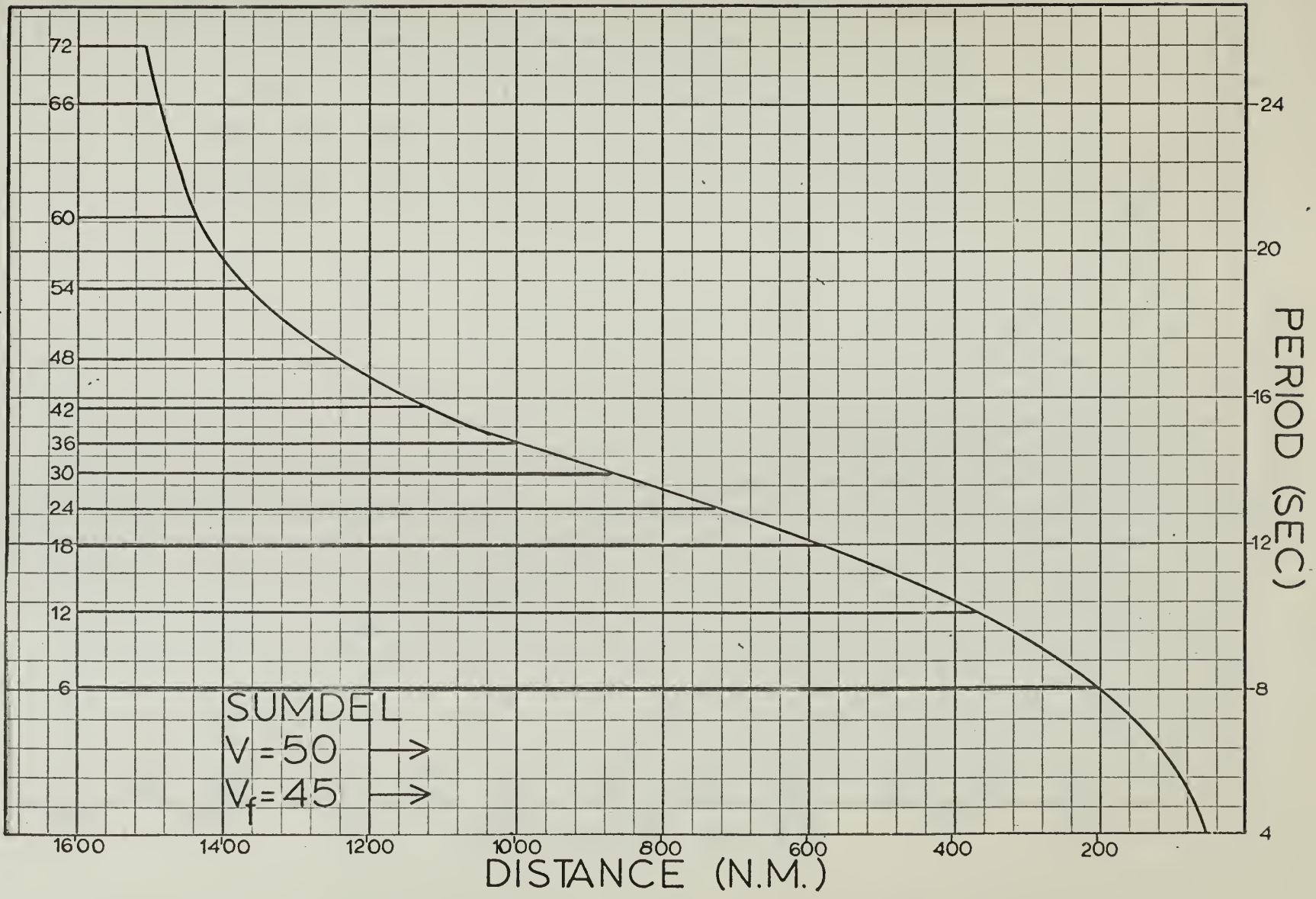


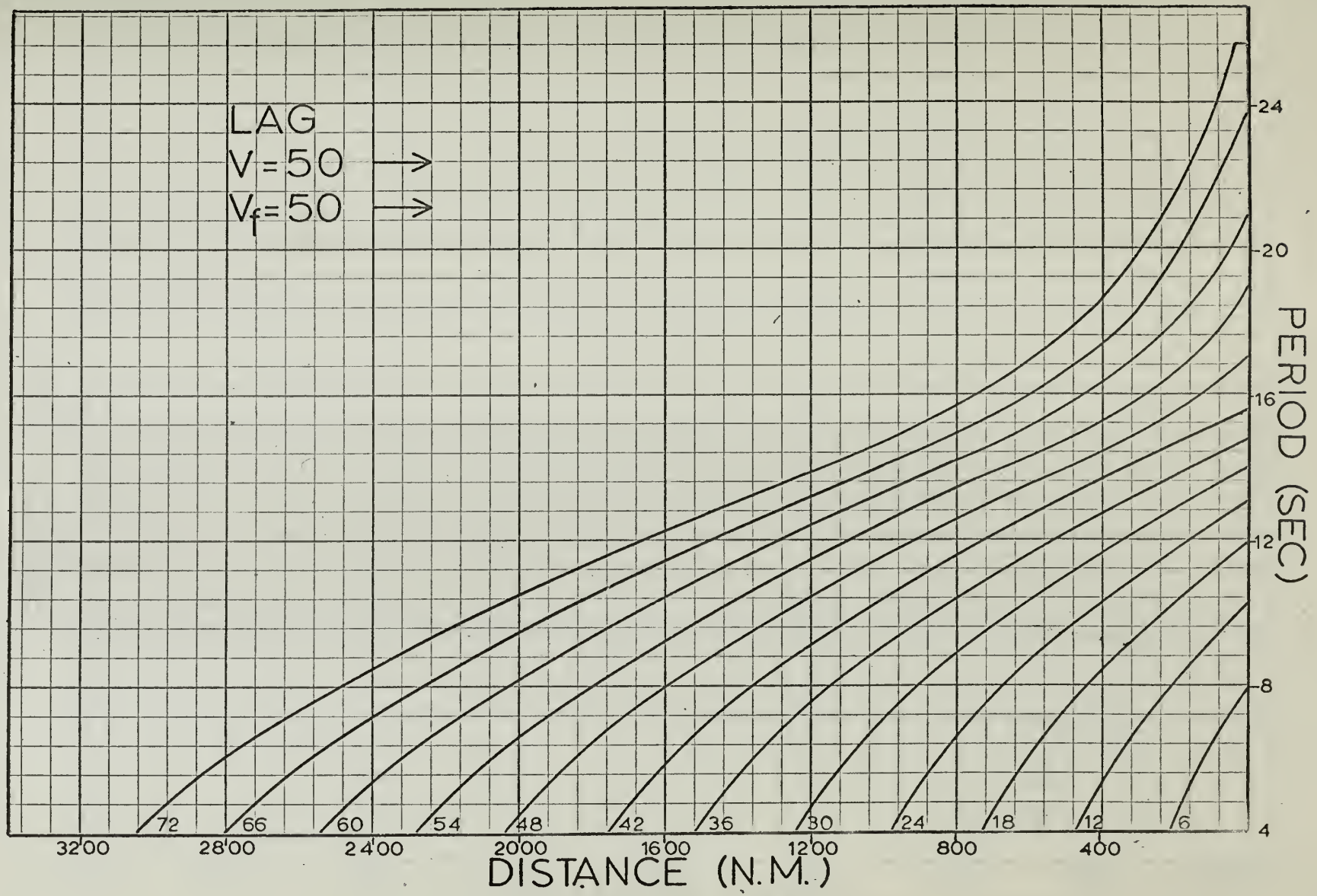

72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V=50
Vf=40
1200
1050
900
750
600
450
300
150
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)


LAG
V = 50 →
V_f = 45 →
72
66
60
54
48
42
36
30
24
18
12
6
2800
2450
2100
1750
1400
1050
700
350
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

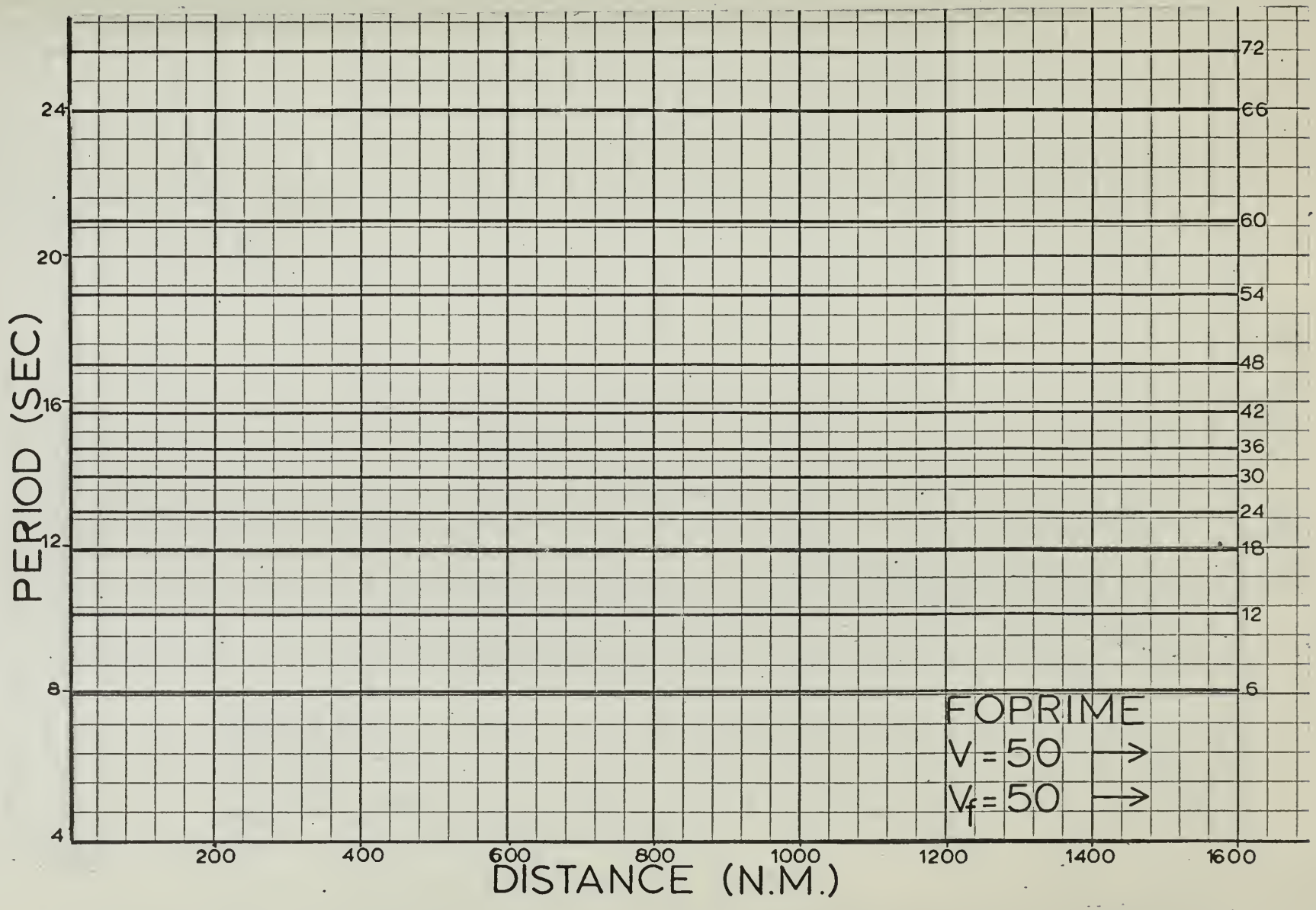



PERIOD (SEC)
4
8
12
16
20
24
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 50 →
Vf = 45 →

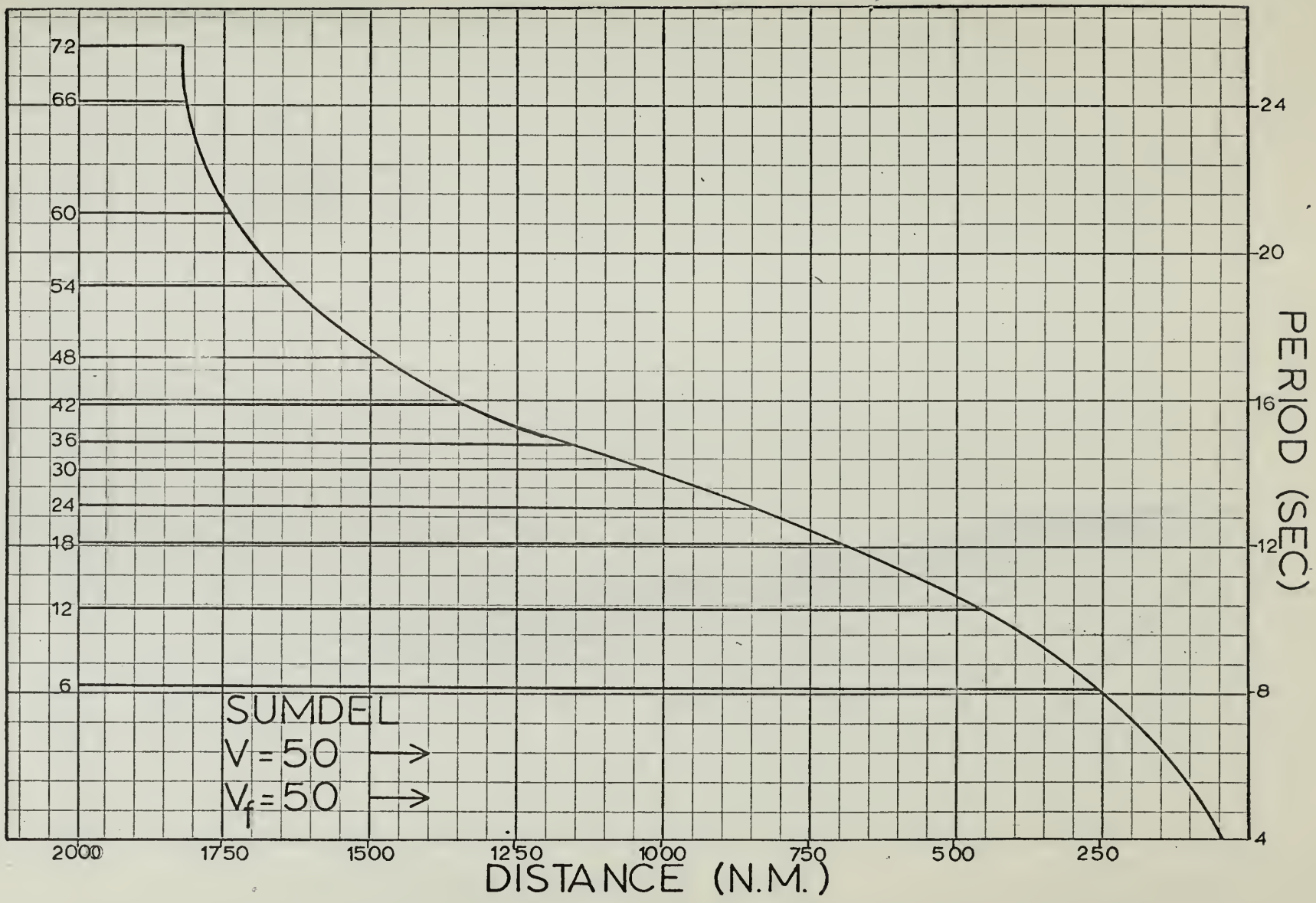

72
66
60
54
48
42
36
30
24
18
12
6
24
20
16
12
8
4
PERIOD (SEC)
SUMDEL
V=50 →
V_f=45 →
16'00
14'00
12'00
10'00
800
600
400
200
DISTANCE (N.M.)


LAG
V = 50 →
Vf = 50 →
72
66
60
54
48
42
36
30
24
18
12
6
32'00
28'00
24'00
20'00
16'00
12'00
800
400
DISTANCE (N.M.)
4
8
12
16
20
24
PERIOD (SEC)

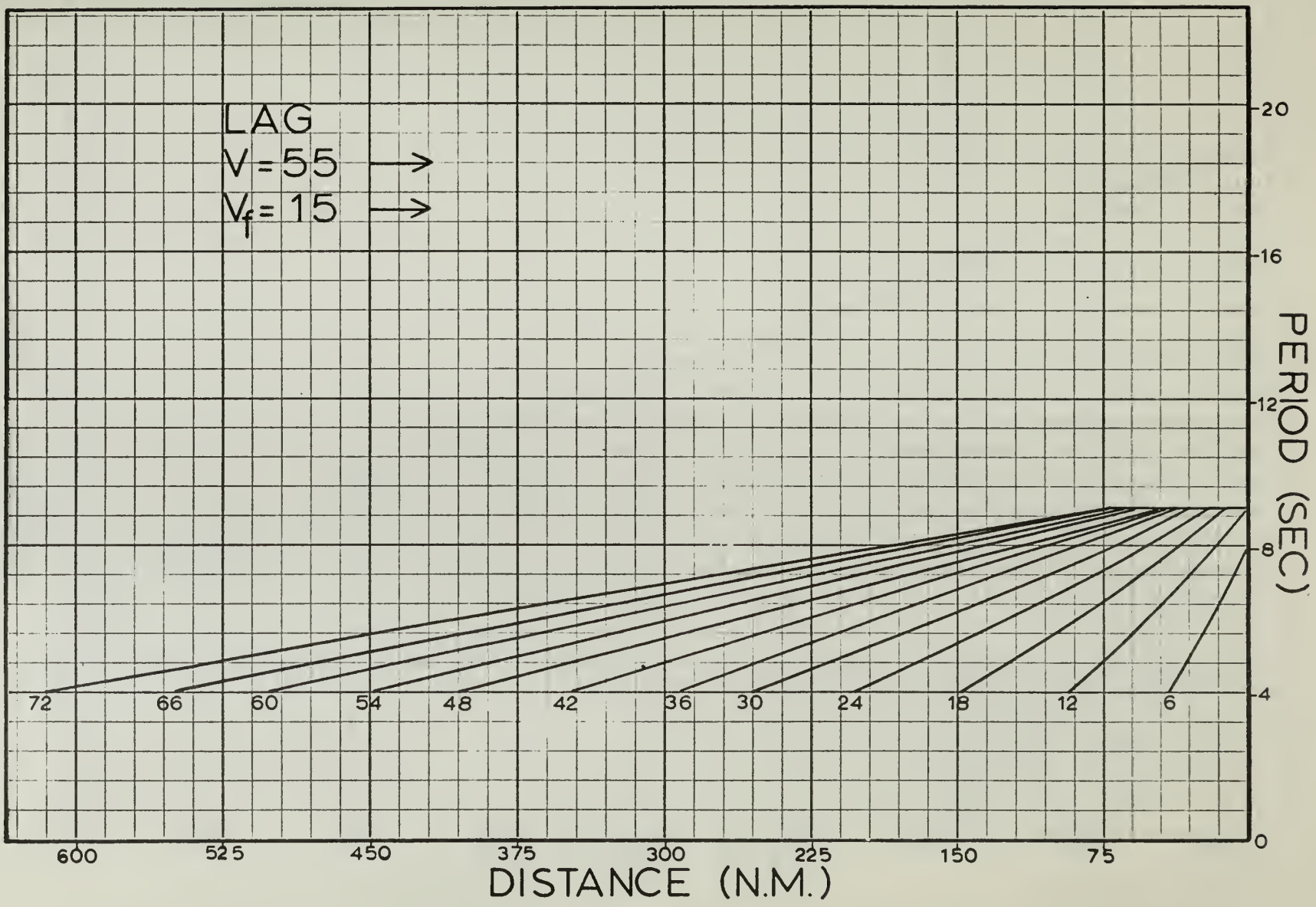


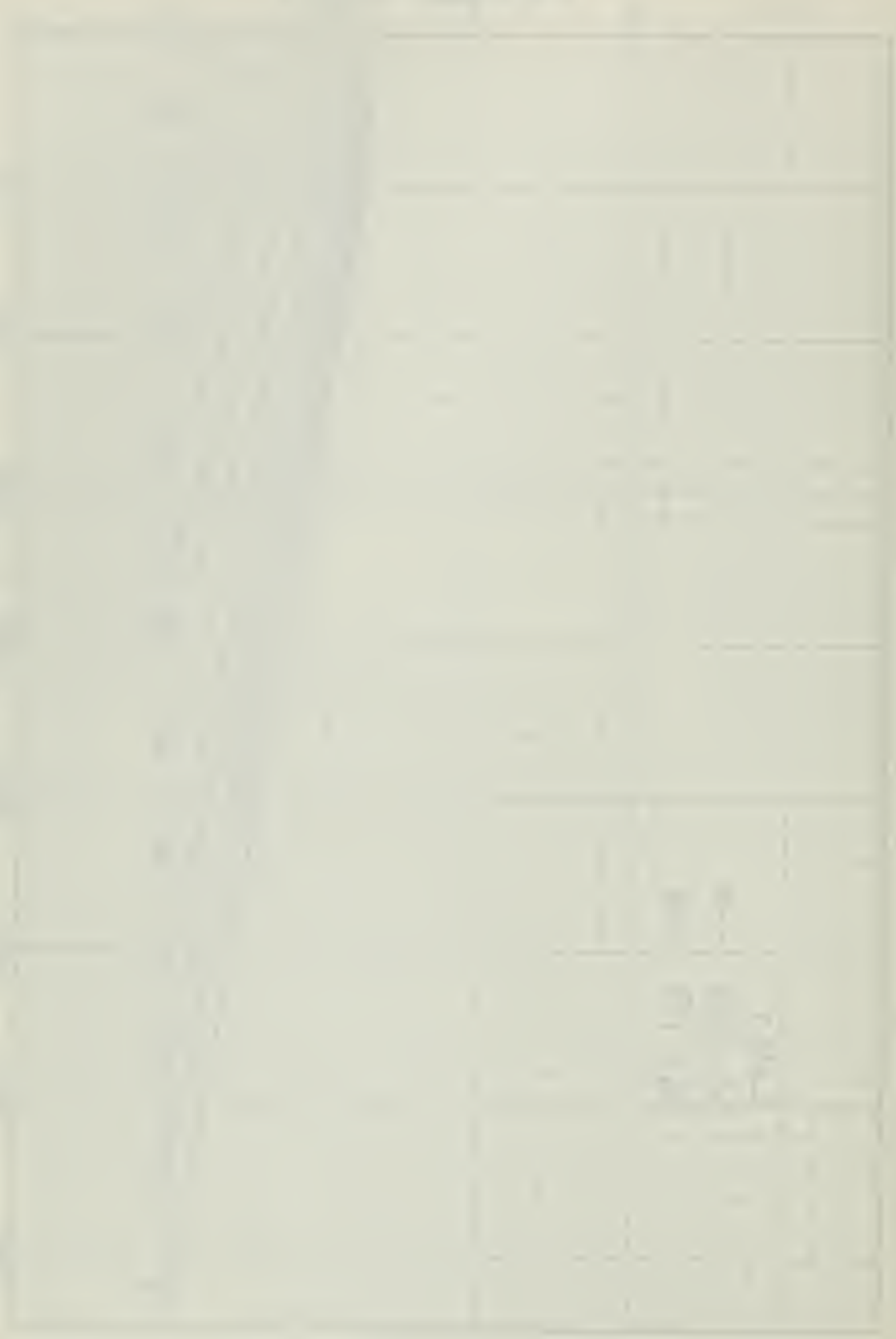

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
FOPRIME
V = 50 →
Vf = 50 →

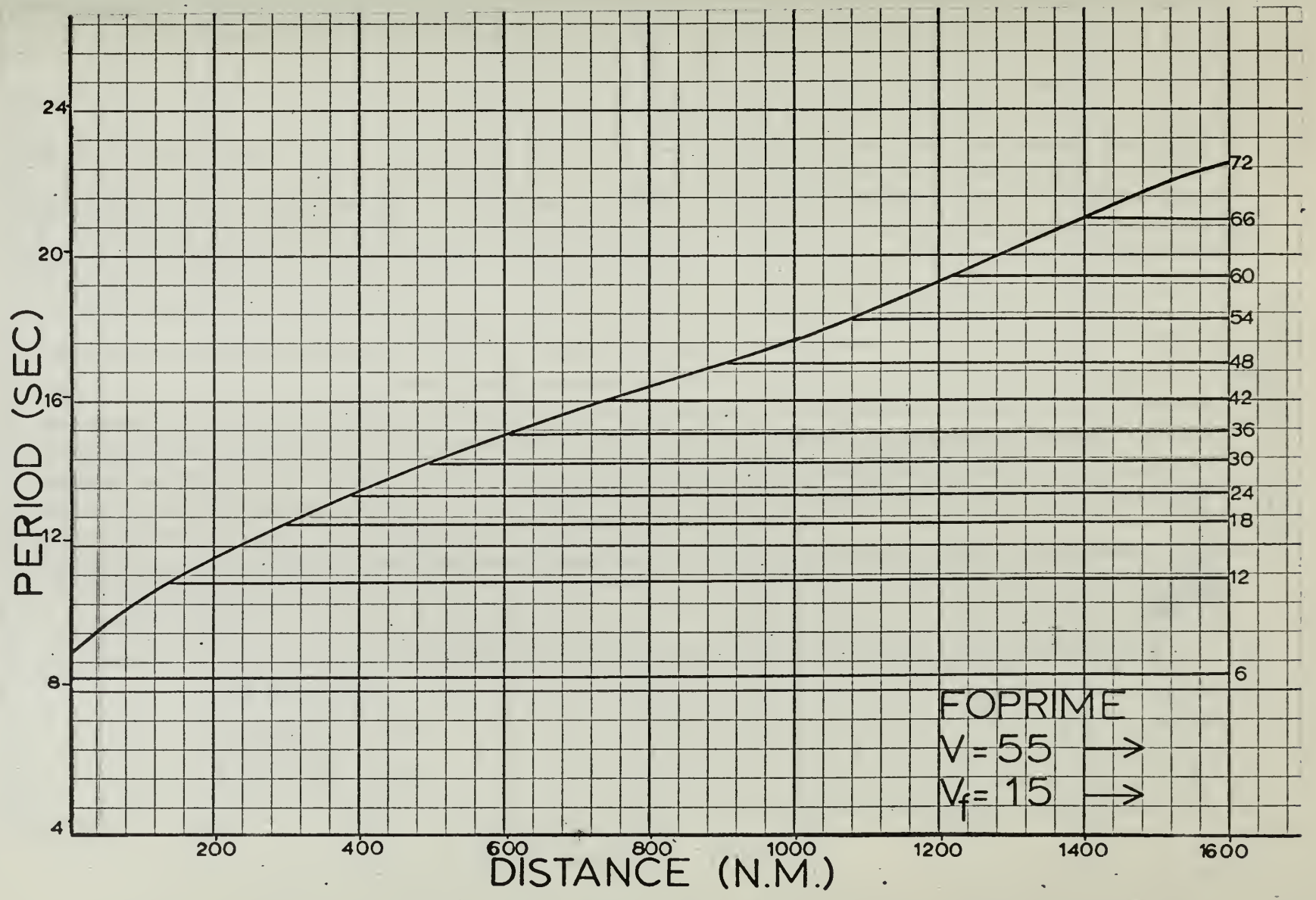



72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 50 →
V_f = 50 →
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

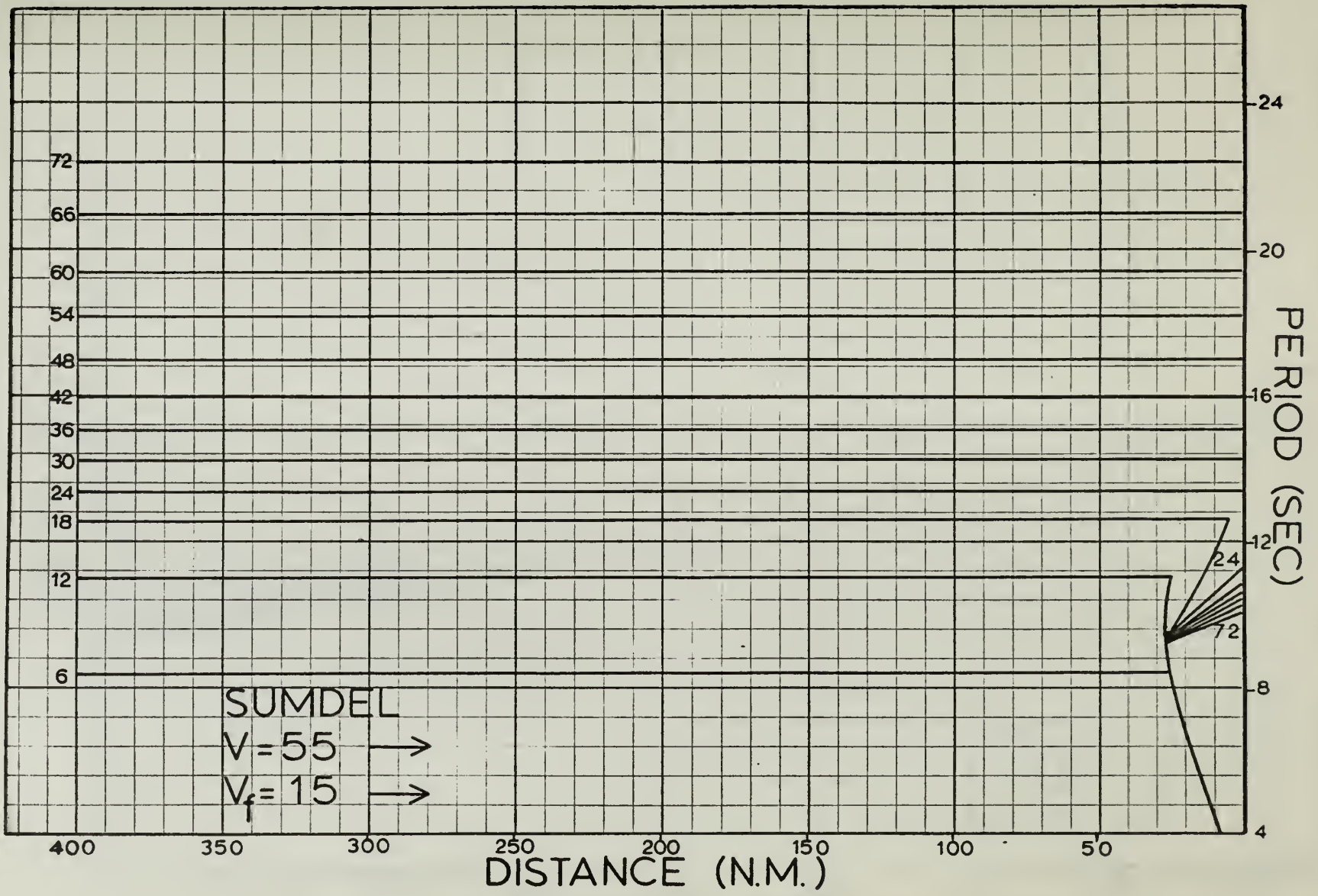


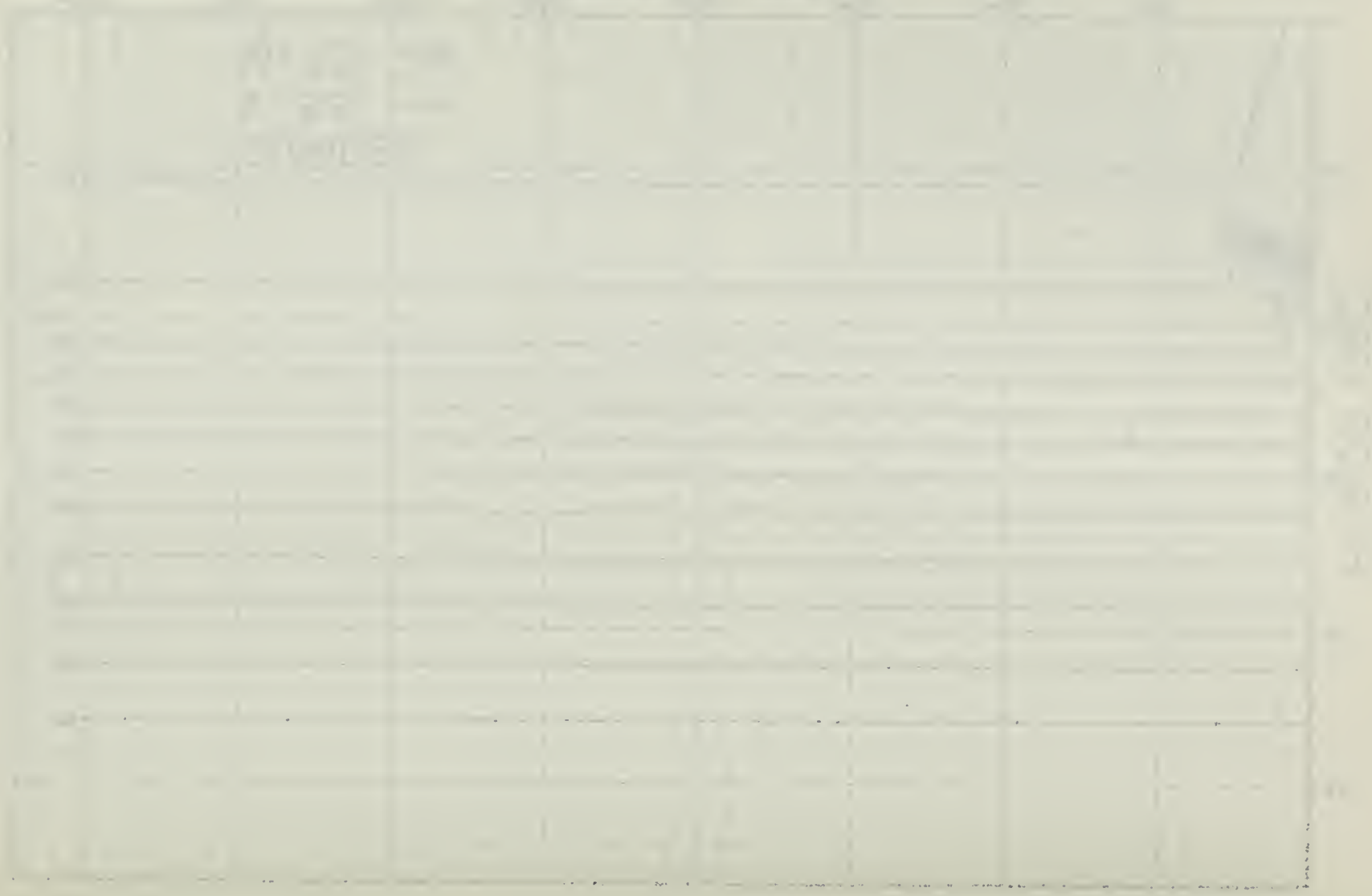

LAG
V = 55 →
Vf = 15 →
72
66
60
54
48
42
36
30
24
18
12
6
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

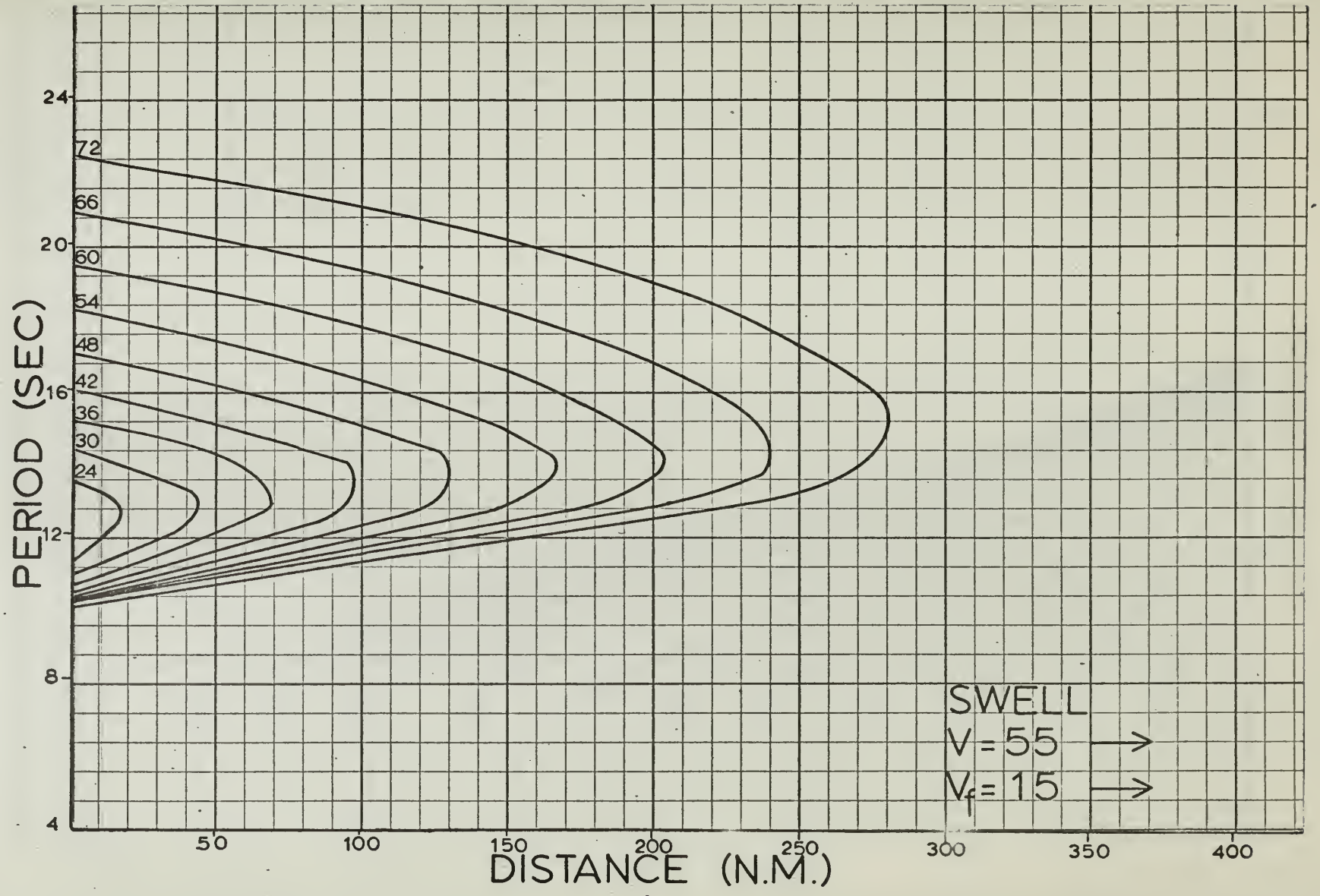


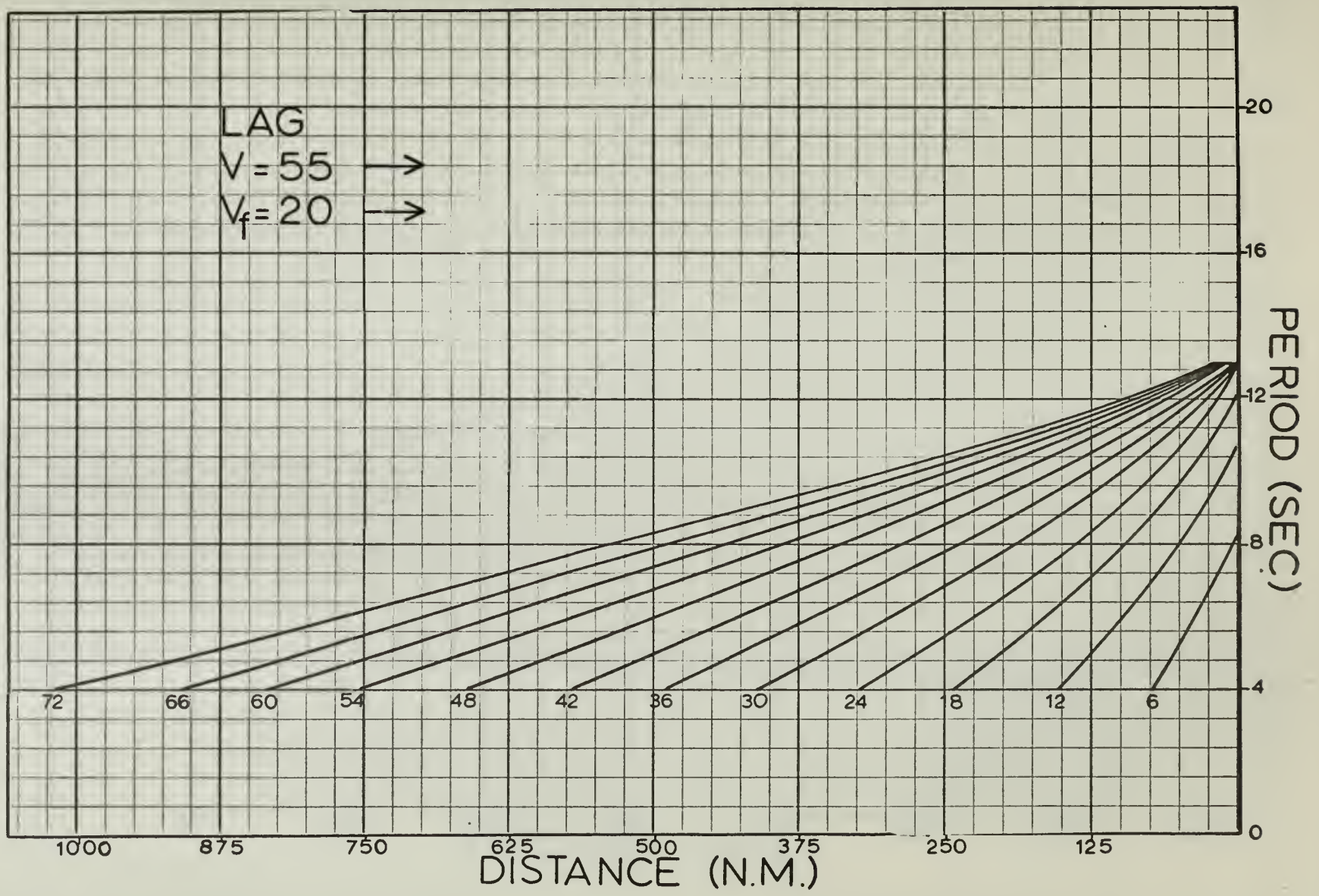

PERIOD (SEC)
24
20
16
12
8
4
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 55
Vf = 15



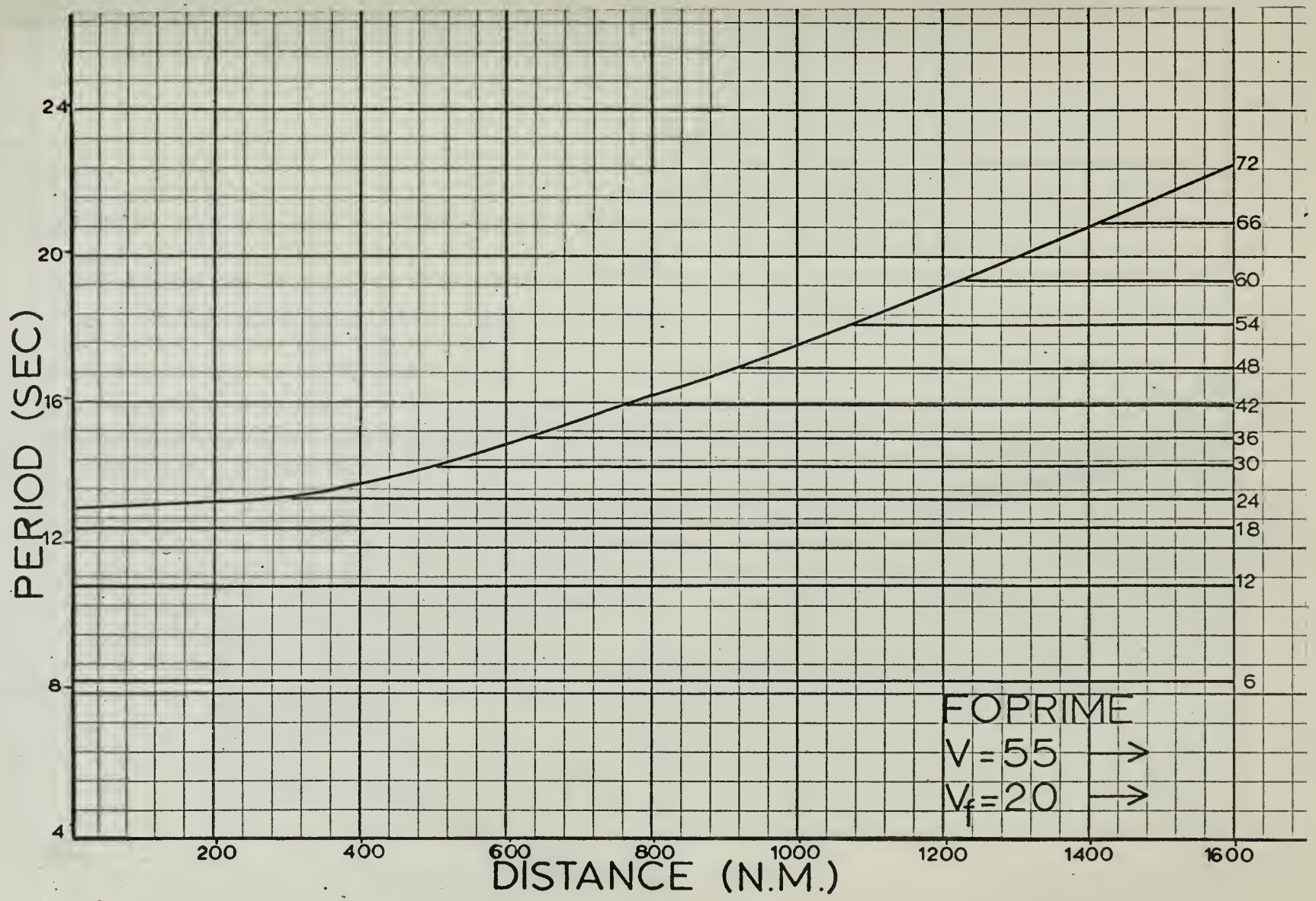

72
66
60
54
48
42
36
30
24
18
12
6
24
20
16
12
8
4
PERIOD (SEC)
24
72
SUMDEL
V=55 →
Vf=15 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)



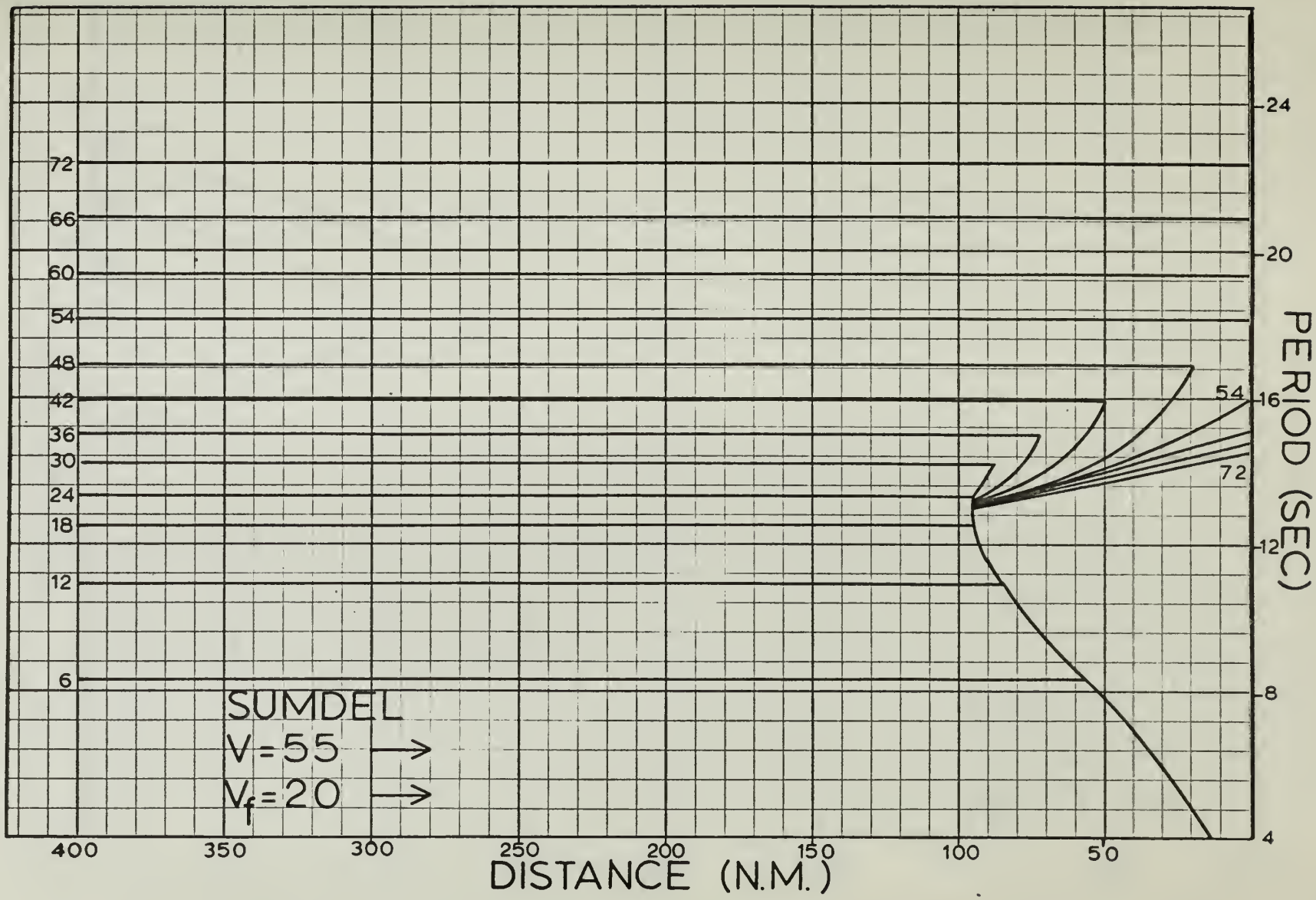

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V = 55
V_f = 15


LAG
V = 55 →
Vf = 20 →
72
66
60
54
48
42
36
30
24
18
12
6
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC.)

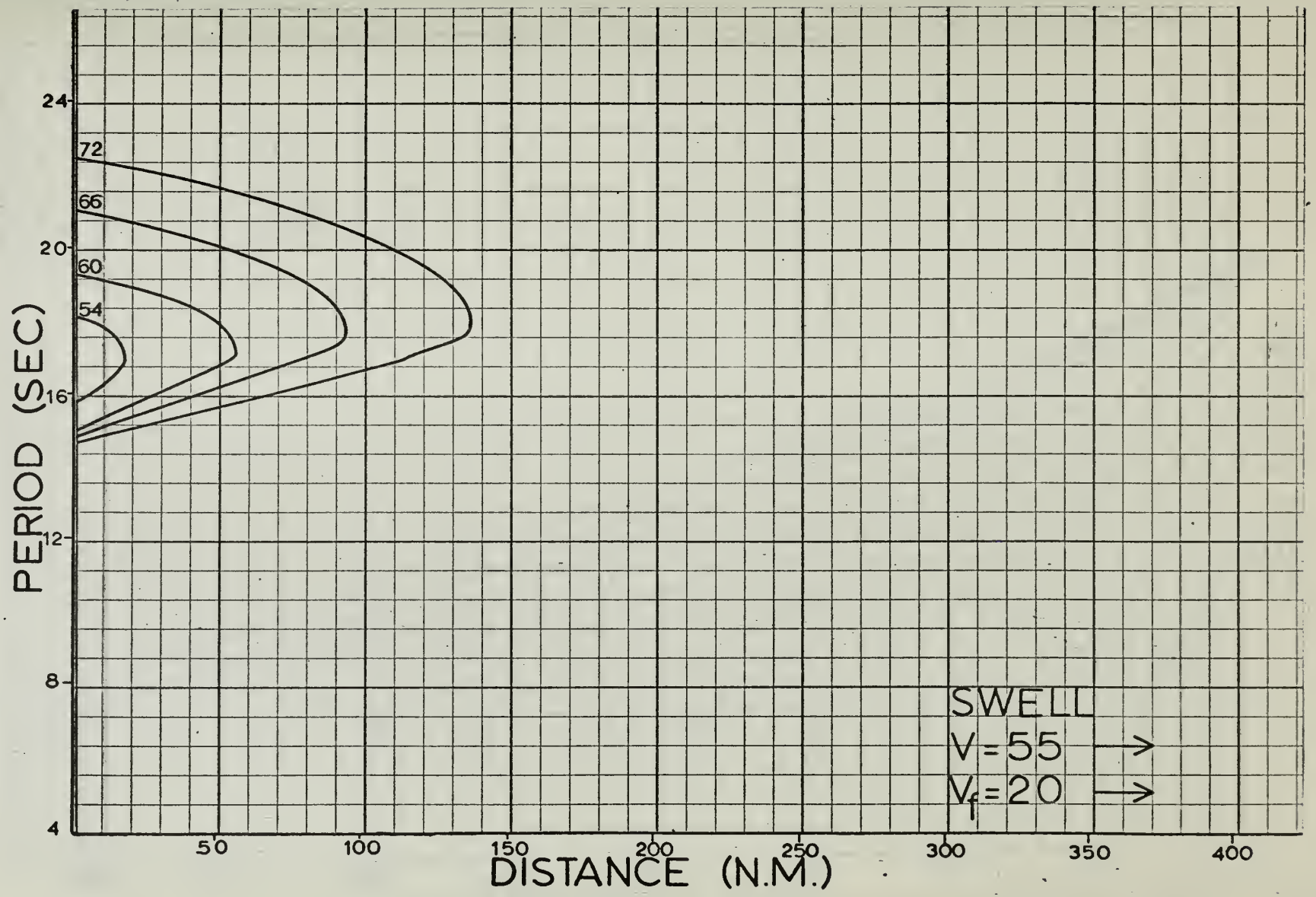



PERIOD (SEC)
24
20
16
12
8
4
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V=55 →
Vf=20 →

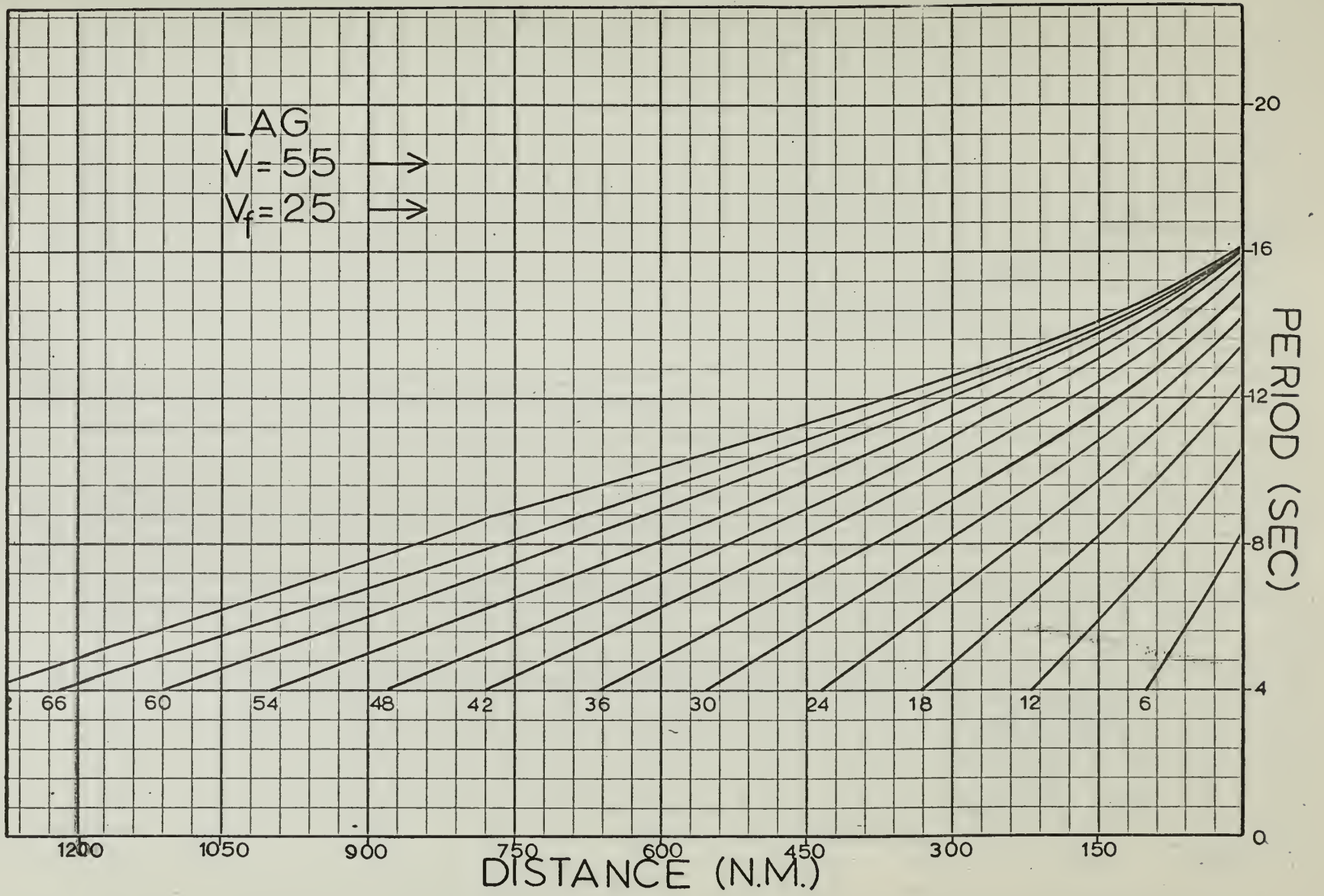


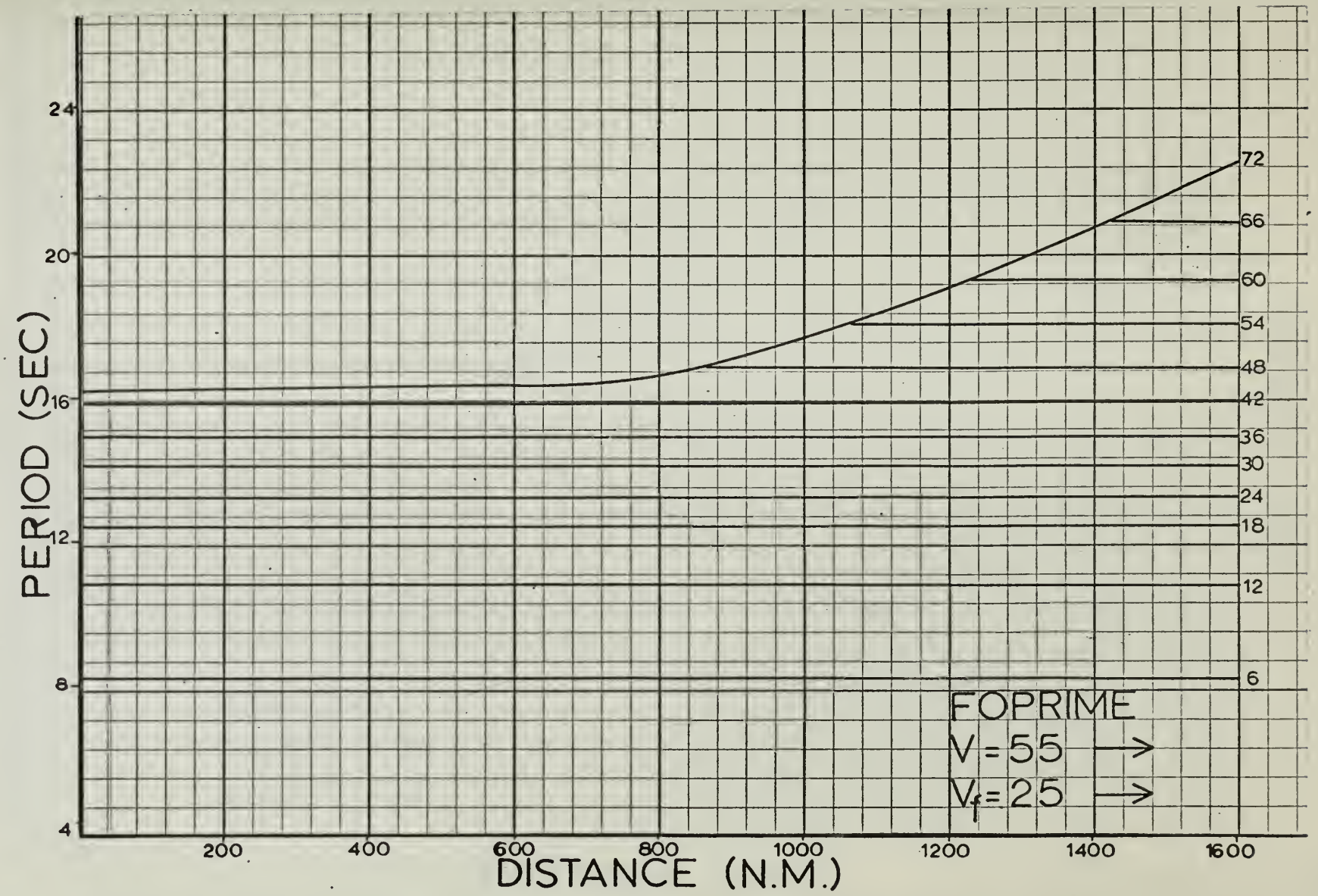

72
66
60
54
48
42
36
30
24
18
12
6
54
72
24
20
16
12
8
4
PERIOD (SEC)
SUMDEL
V=55 →
Vf=20 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)



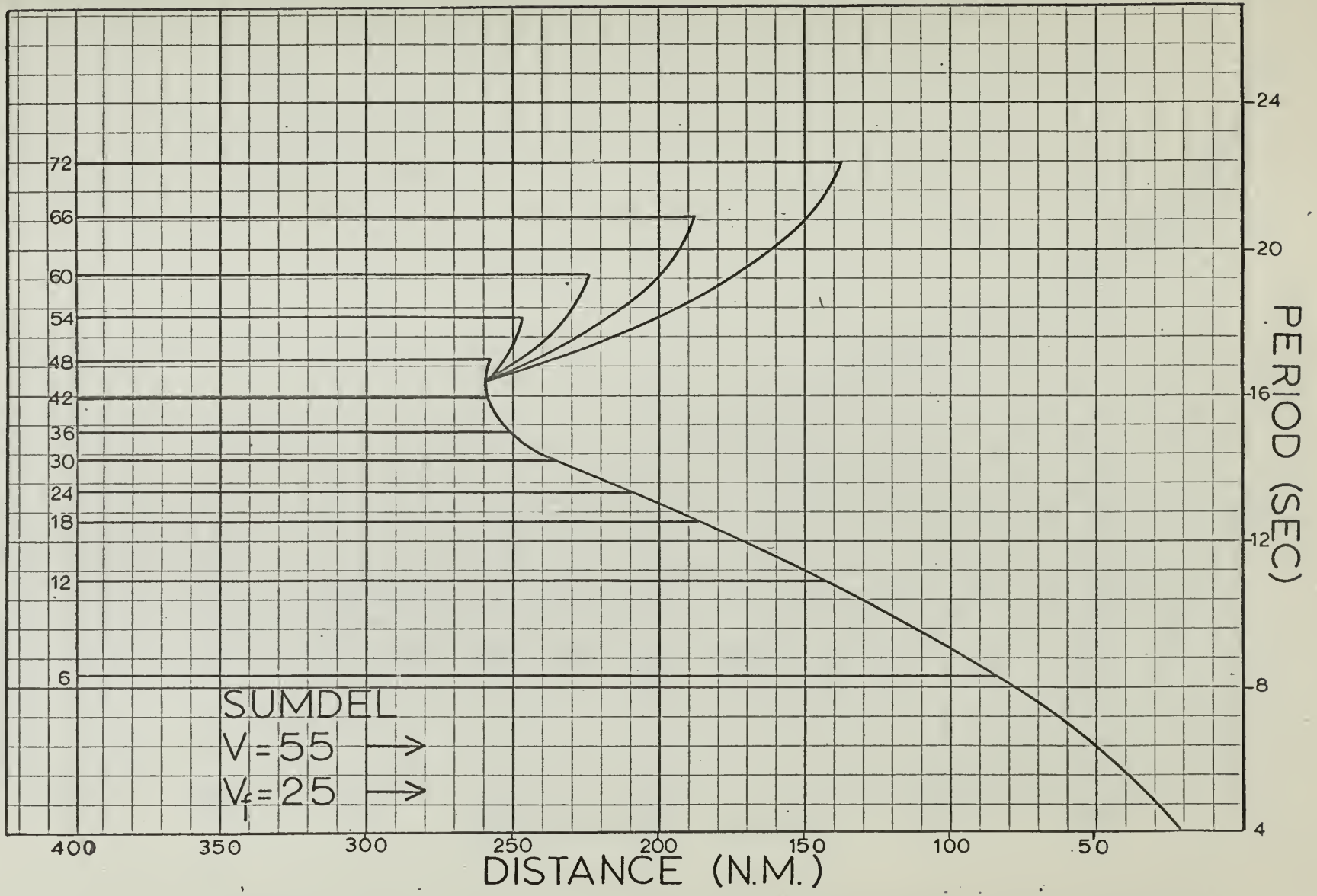

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
50
100
150
200
250
300
350
400
DISTANCE (N.M.)
SWELL
V=55 →
Vf=20 →



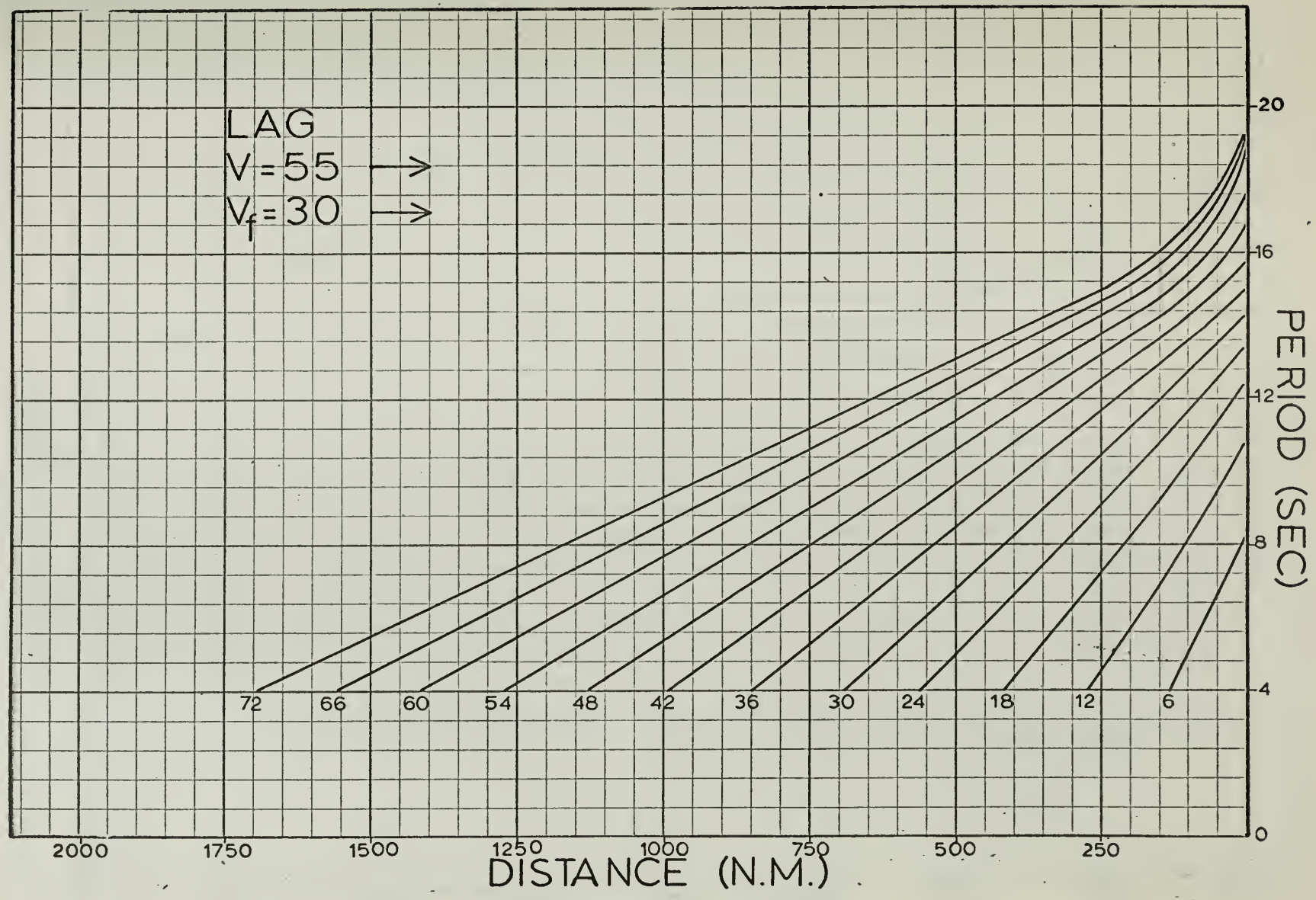

LAG
V = 55 →
Vf = 25 →
66
60
54
48
42
36
30
24
18
12
6
1200
1050
900
750
600
450
300
150
0
4
8
12
16
20
PERIOD (SEC)
DISTANCE (N.M.)

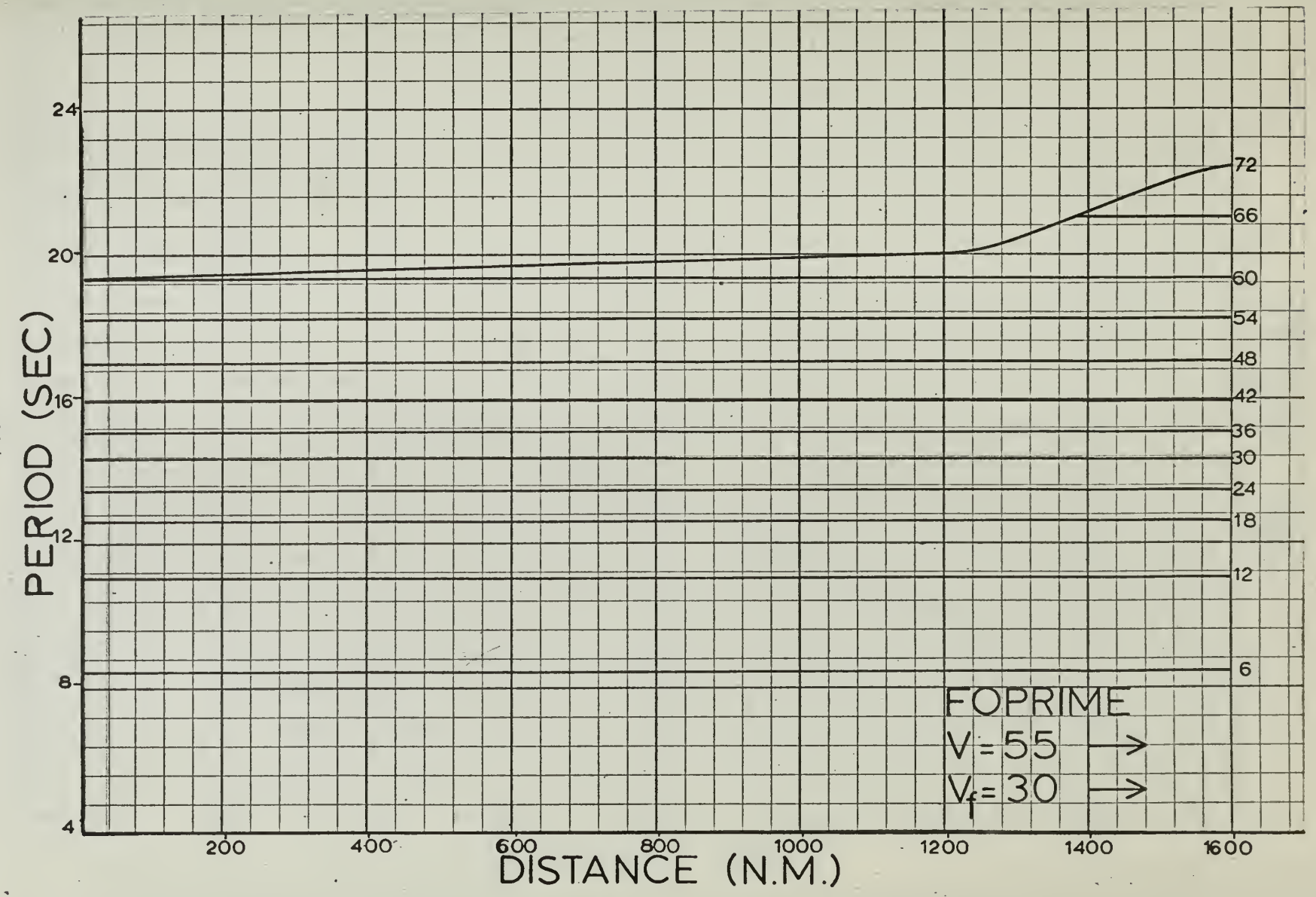

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 55 →
Vf = 25 →
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

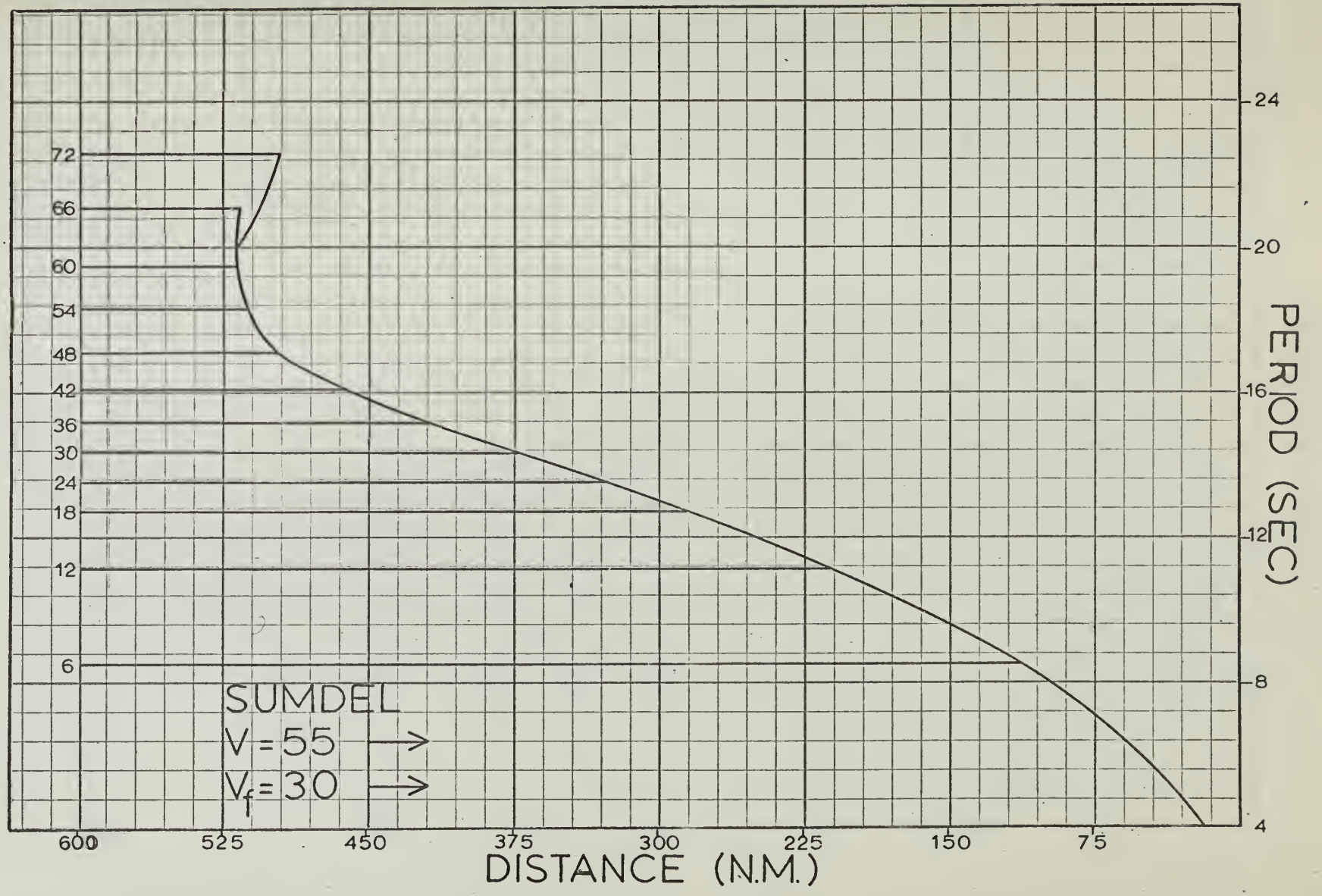


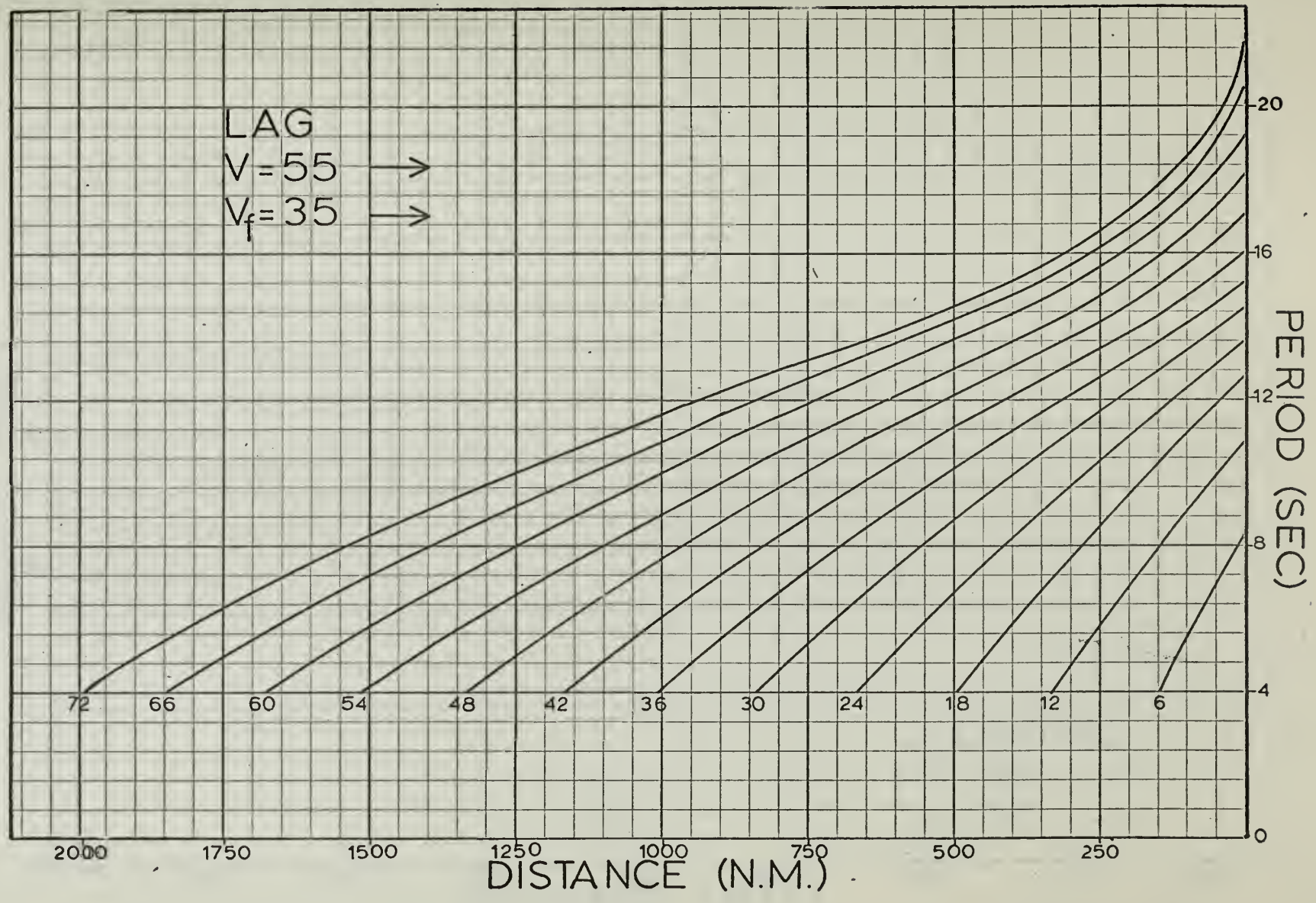

72
66
60
54
48
42
36
30
24
18
12
6
24
20
16
12
8
4
PERIOD (SEC)
SUMDEL
V=55 →
V_f=25 →
400
350
300
250
200
150
100
50
DISTANCE (N.M.)



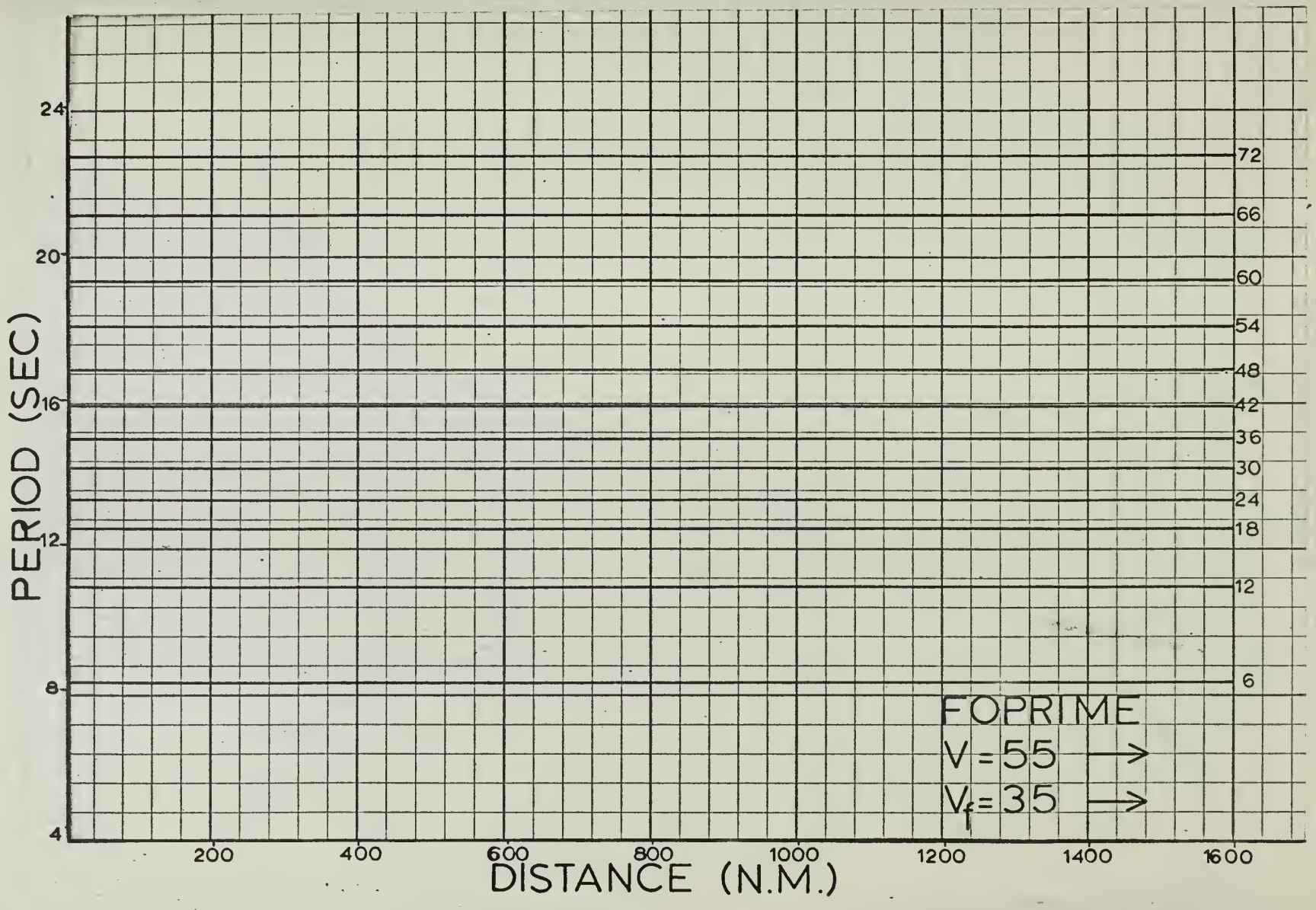

LAG
V = 55 →
V_f = 30 →
72
66
60
54
48
42
36
30
24
18
12
6
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

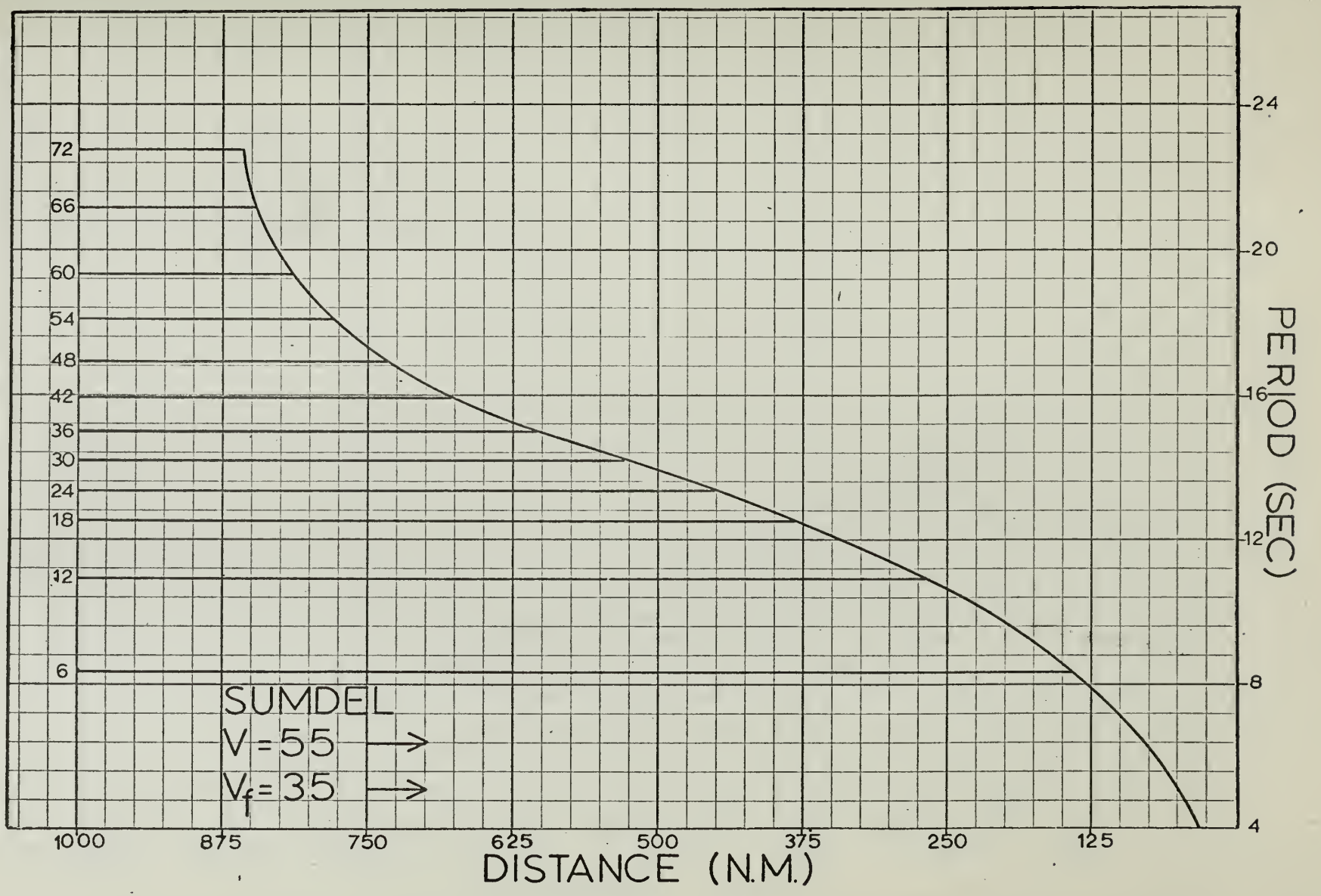

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 55 →
Vf = 30 →
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)


72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55 →
V_f = 30 →
600
525
450
375
300
225
150
75
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

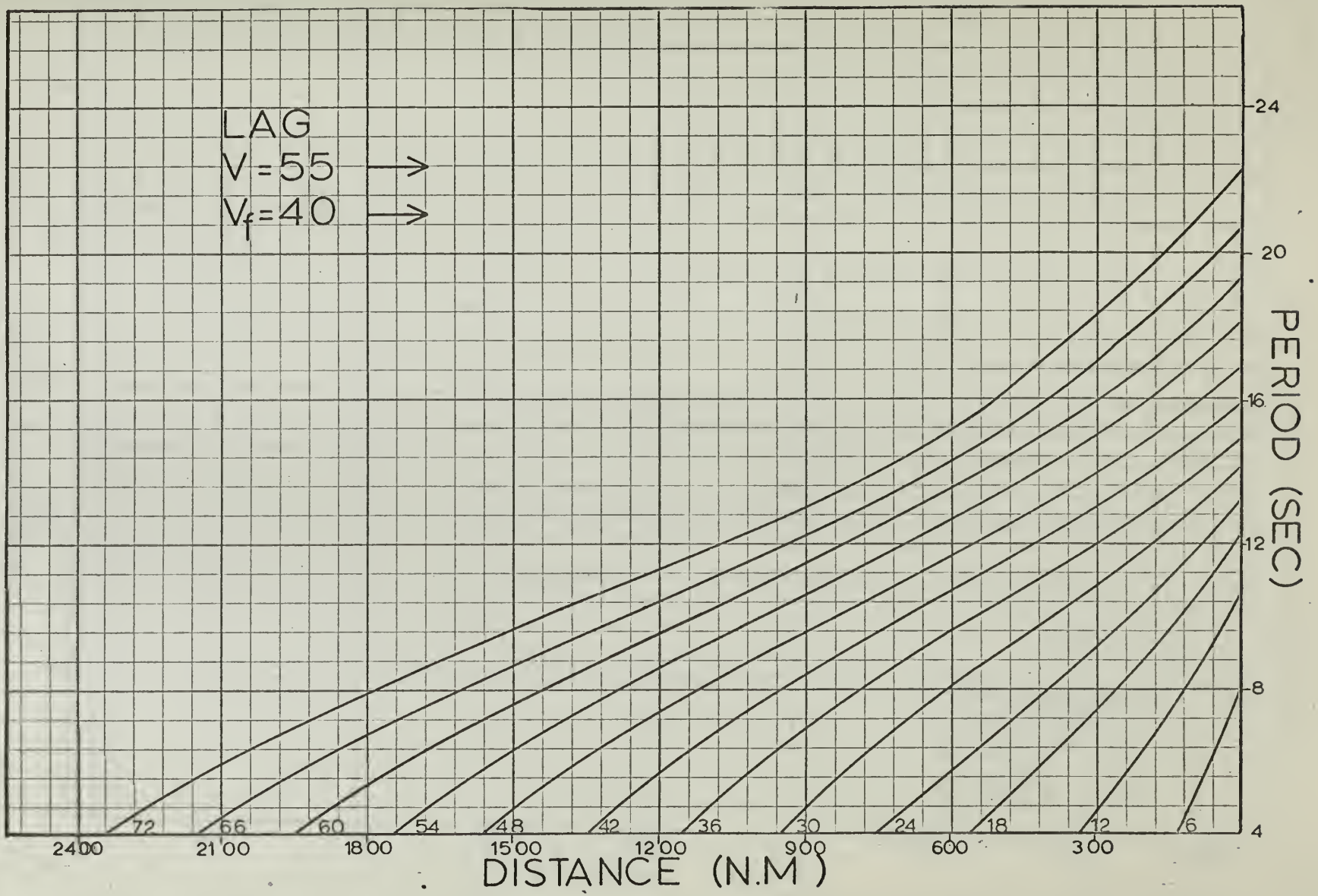

LAG
V = 55 →
V_f = 35 →
72
66
60
54
48
42
36
30
24
18
12
6
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)
0
4
8
12
16
20
PERIOD (SEC)

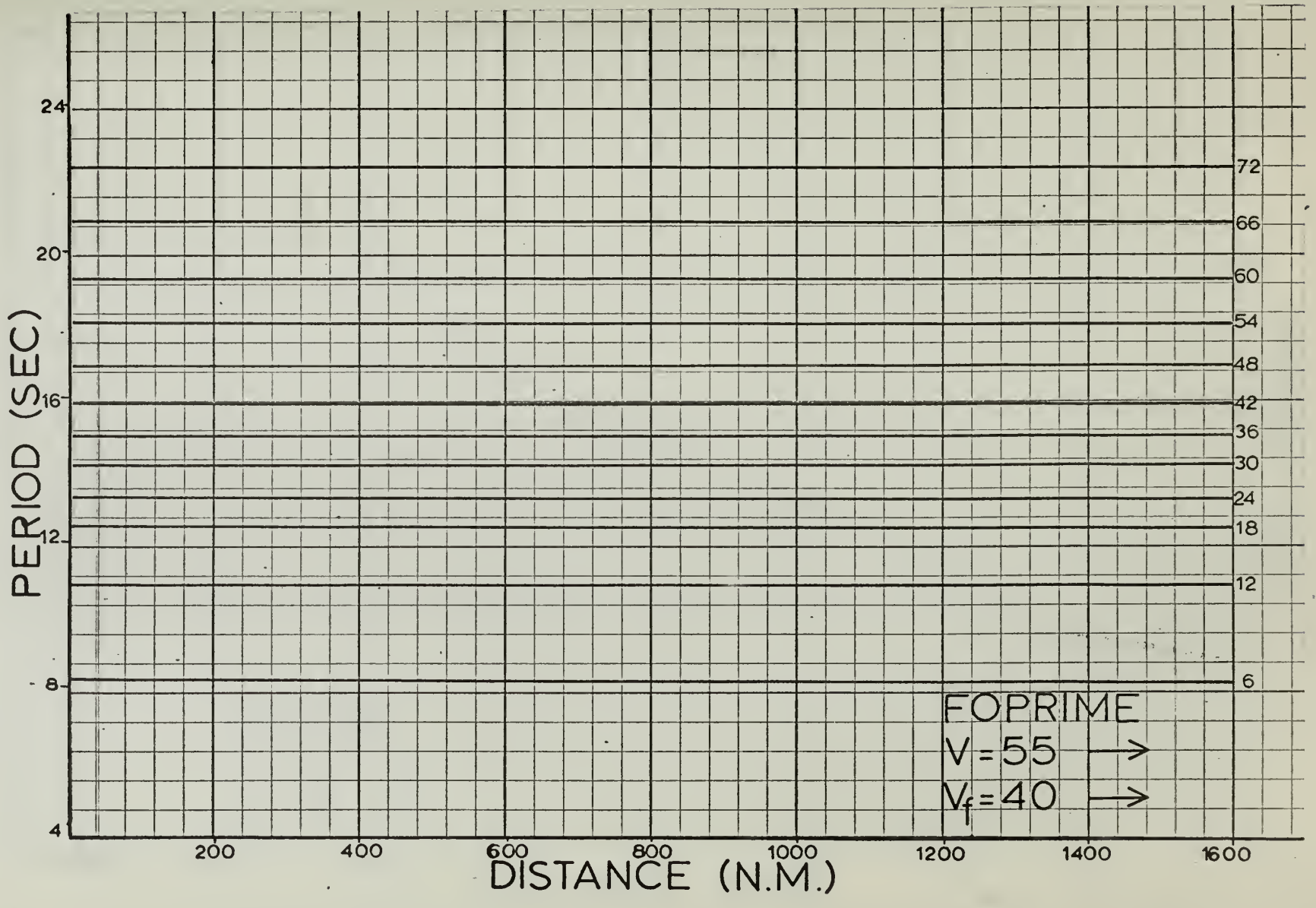



PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 55
V = 35
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

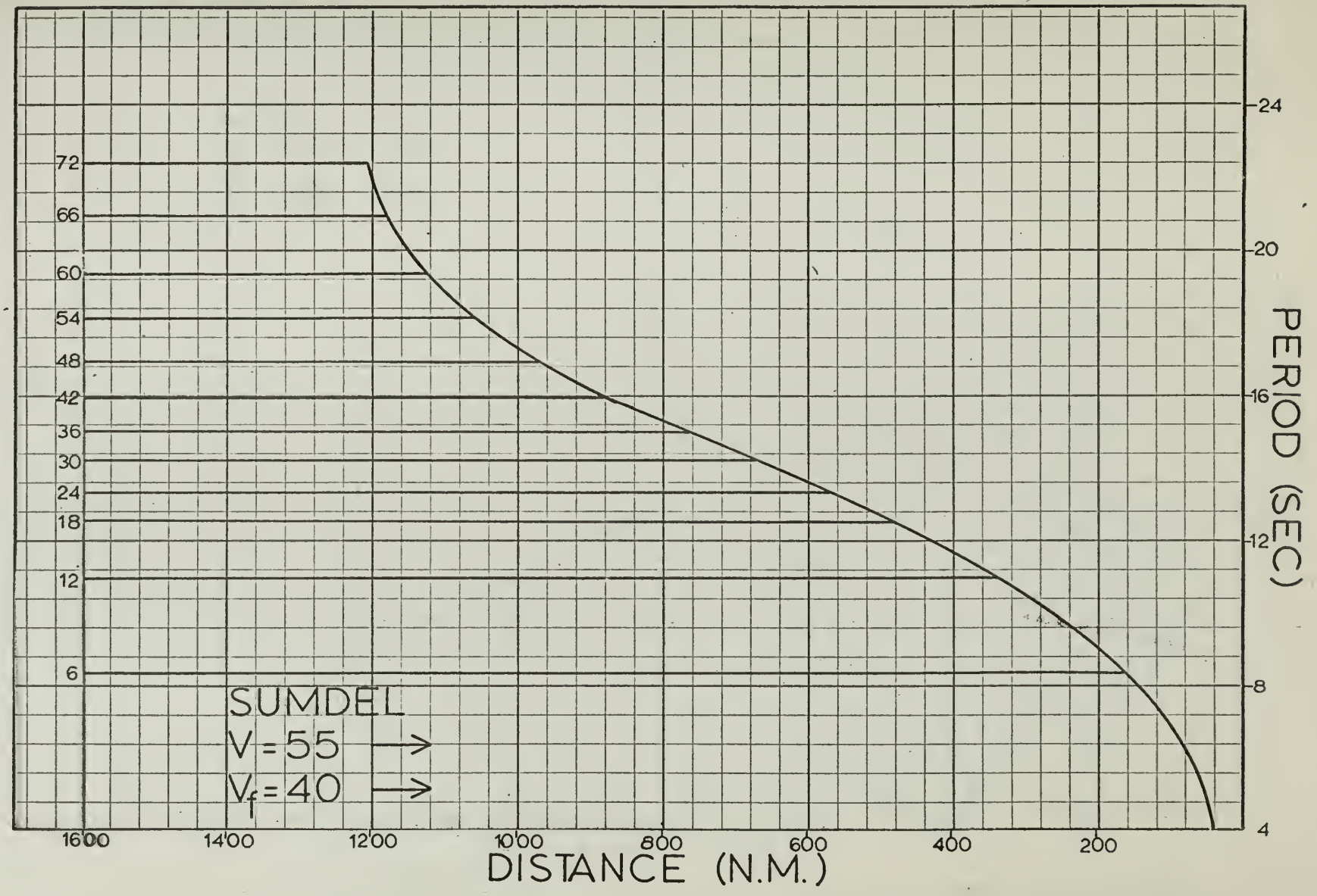

72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55 →
V_f = 35 →
1000
875
750
625
500
375
250
125
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)



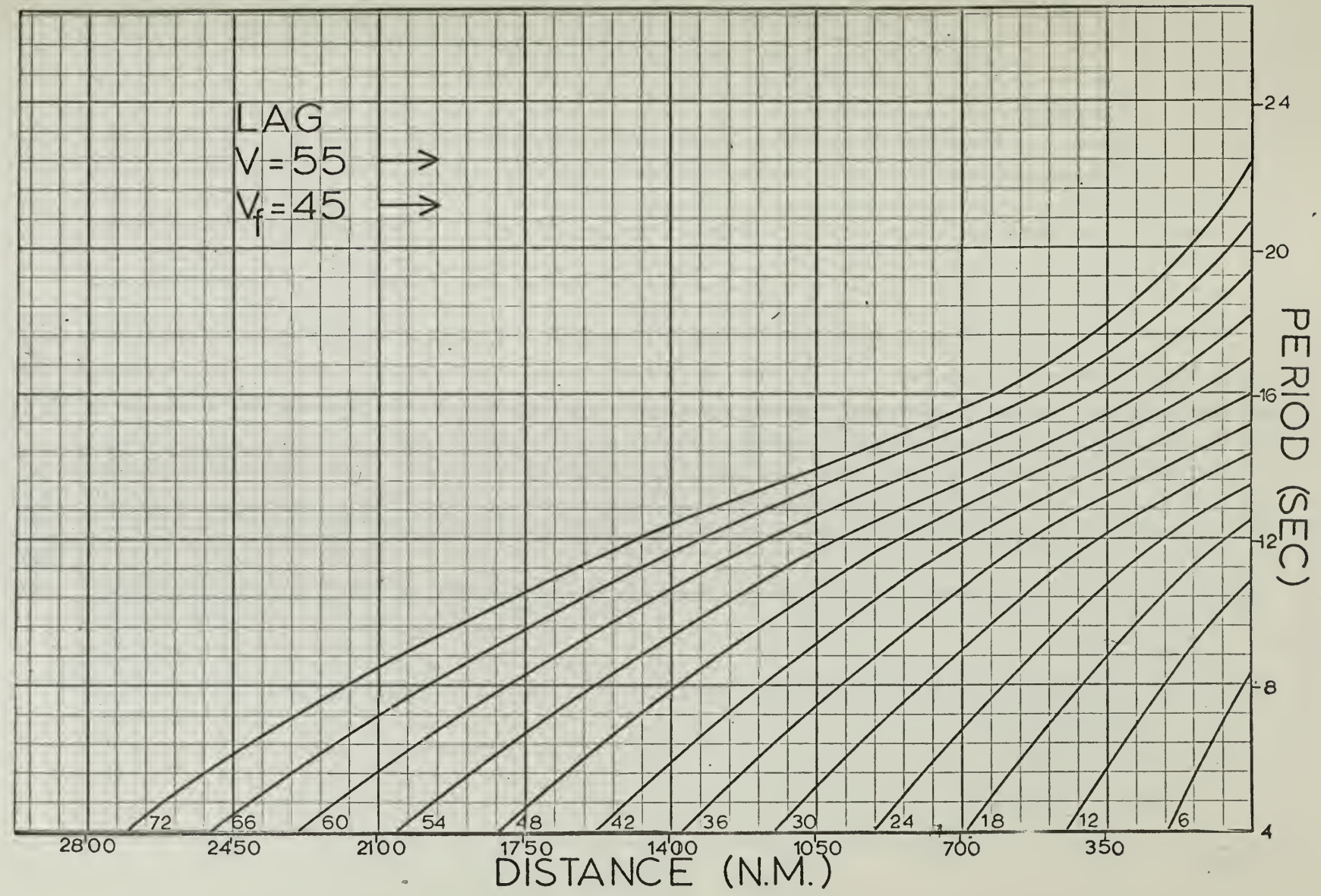

LAG
V=55 →
Vf=40 →
72
66
60
54
48
42
36
30
24
18
12
6
2400
2100
1800
1500
1200
900
600
300
DISTANCE (N.M)
4
8
12
16
20
24
PERIOD (SEC)

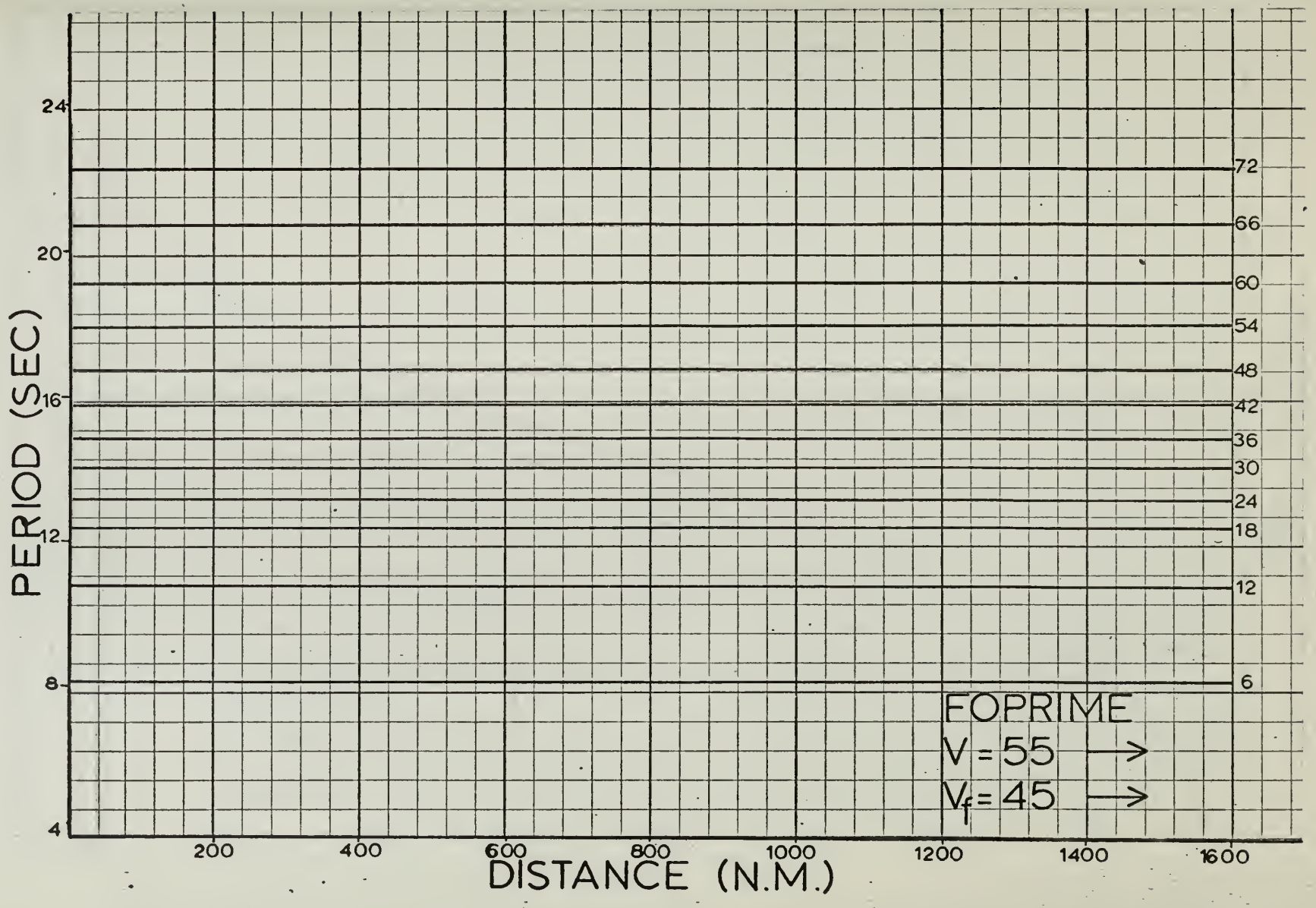

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V=55 →
V_f=40 →
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)



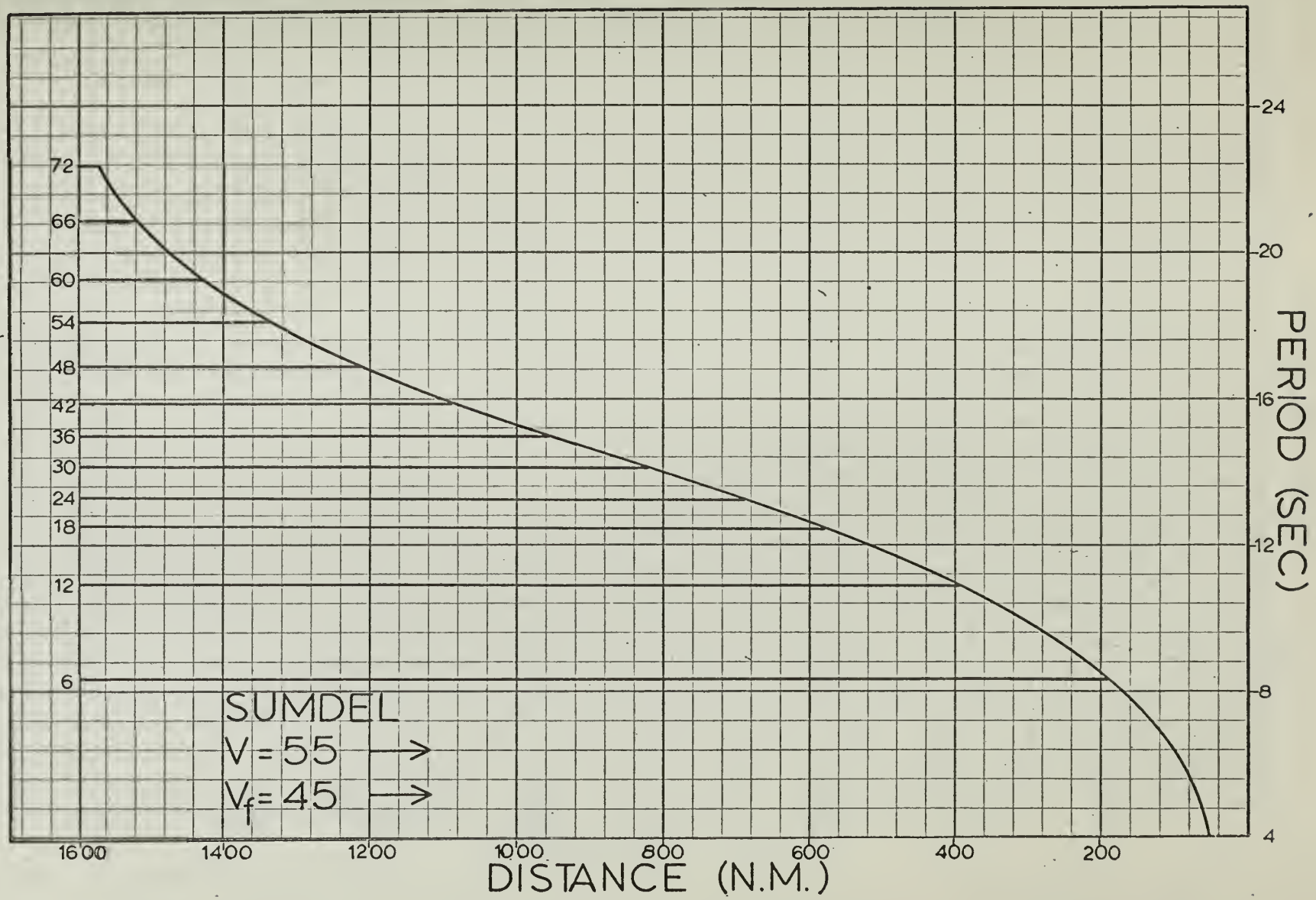

72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55 →
Vf = 40 →
16'00
14'00
12'00
10'00
800
600
400
200
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

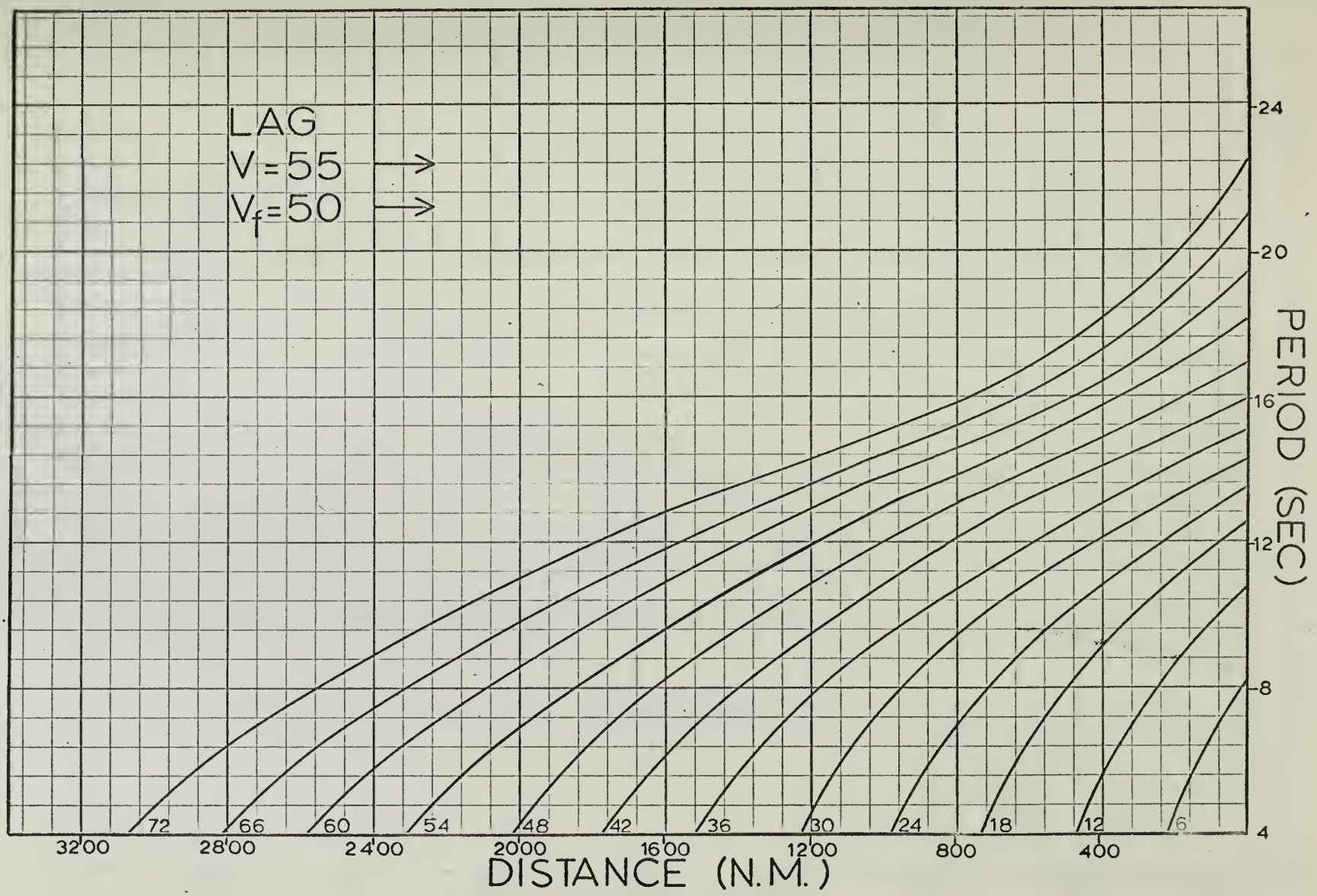



LAG
V = 55 →
V_f = 45 →
72
66
60
54
48
42
36
30
24
18
12
6
2800
2450
2100
1750
1400
1050
700
350
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

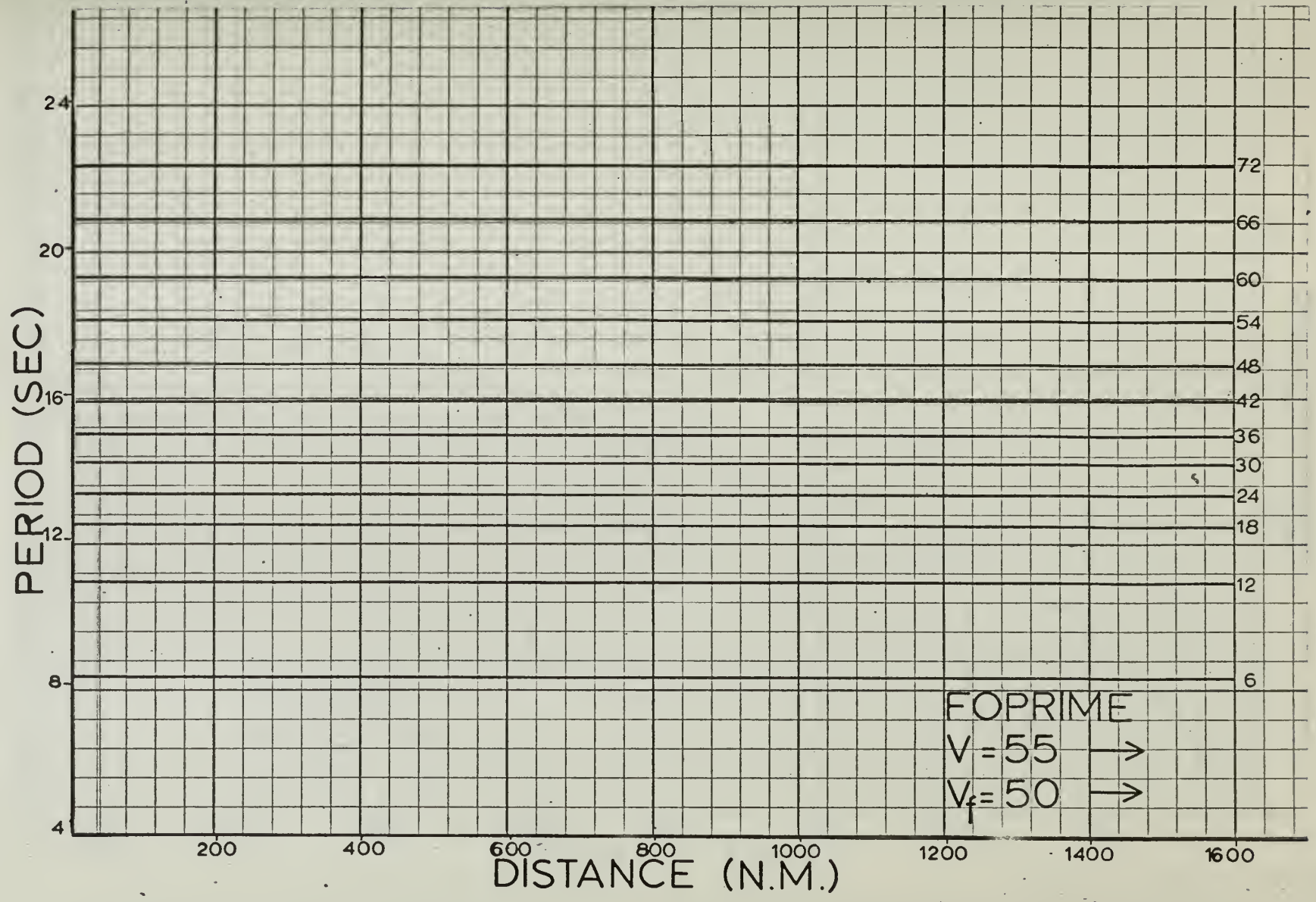

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
FOPRIME
V = 55 →
Vf = 45 →



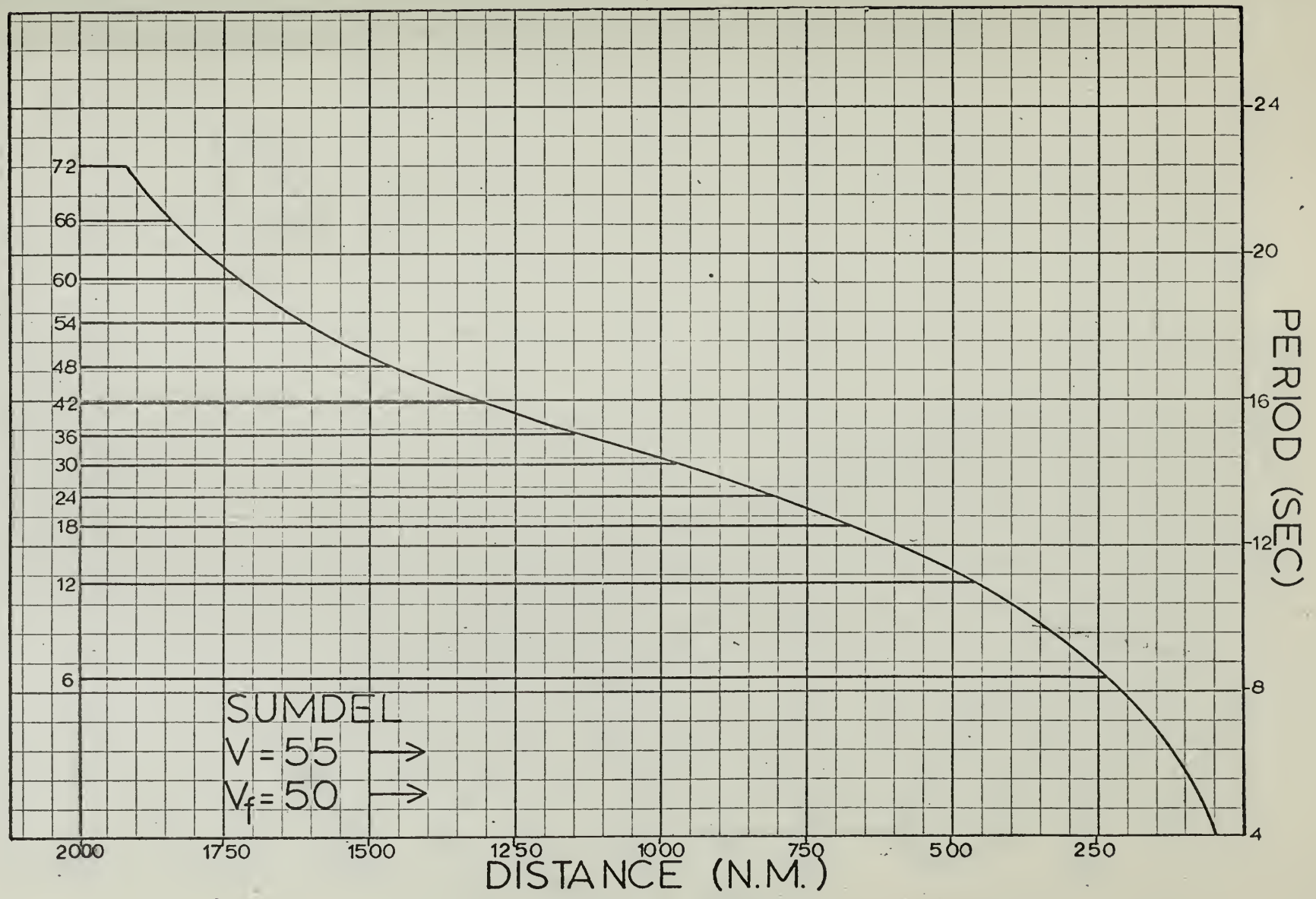

72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55 →
Vf = 45 →
1600
1400
1200
1000
800
600
400
200
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)


LAG
V=55 →
Vf=50 →
72
66
60
54
48
42
36
30
24
18
12
6
32'00
28'00
24'00
20'00
16'00
12'00
800
400
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)

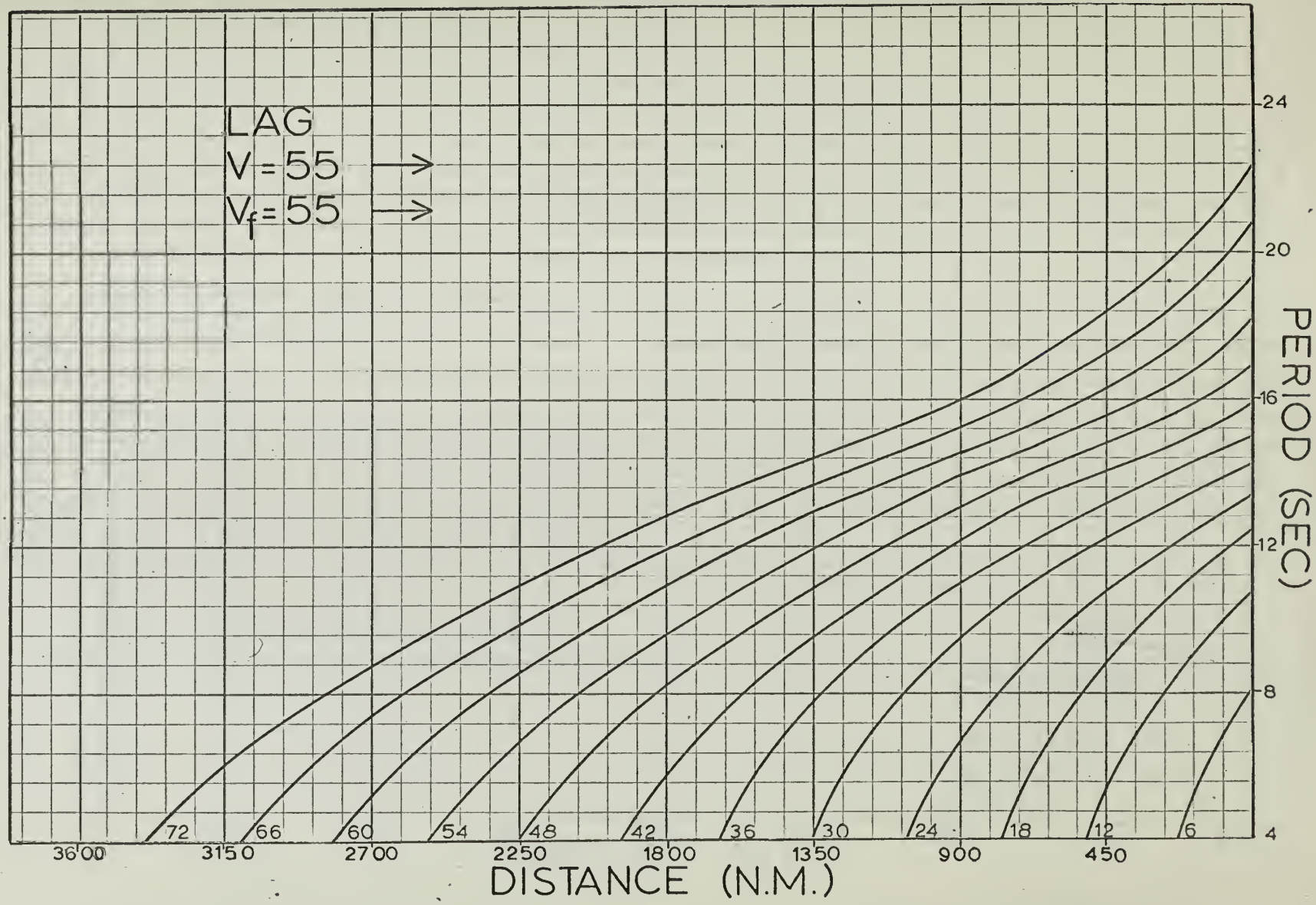


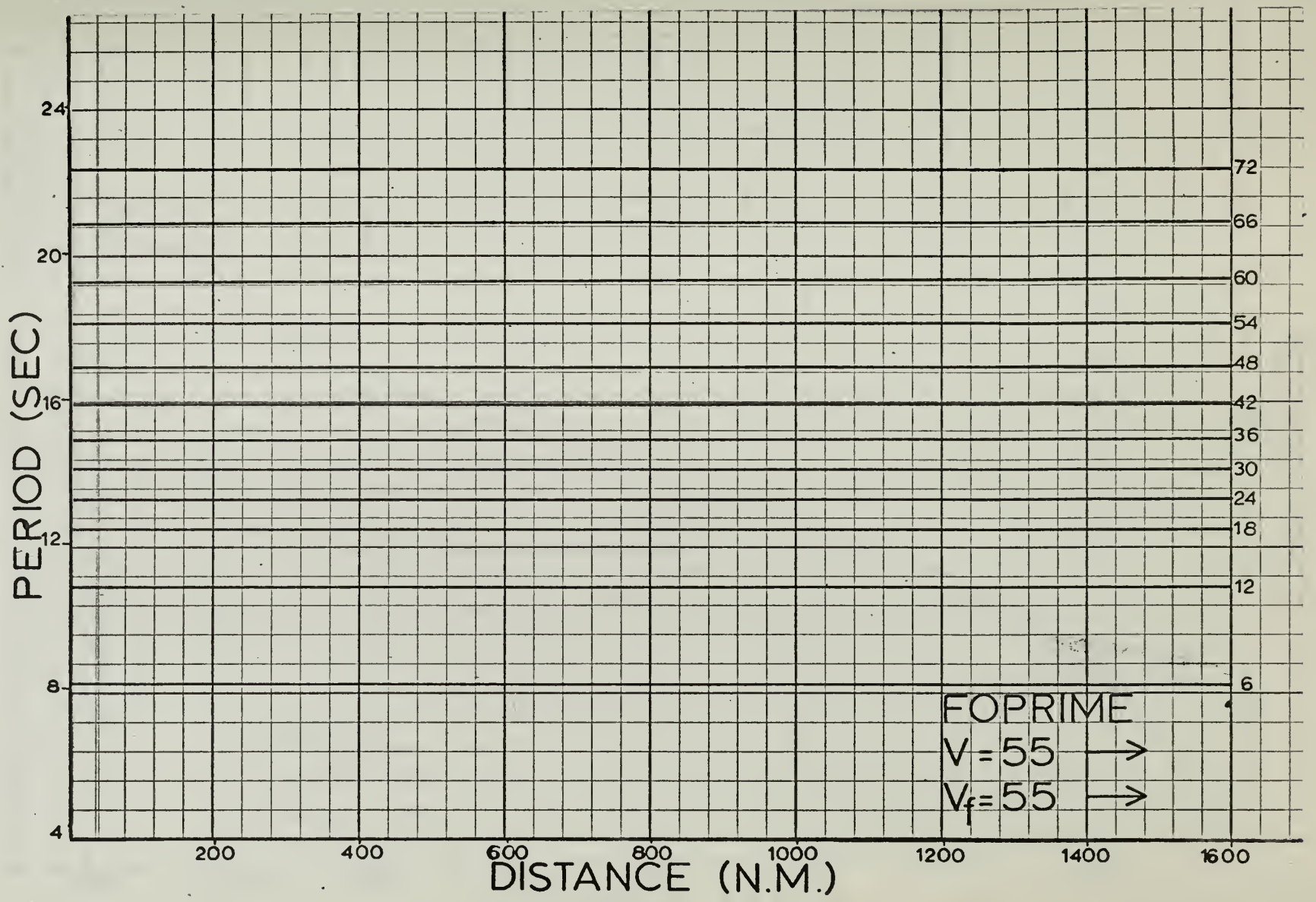

PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 55 →
Vf = 50 →
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)



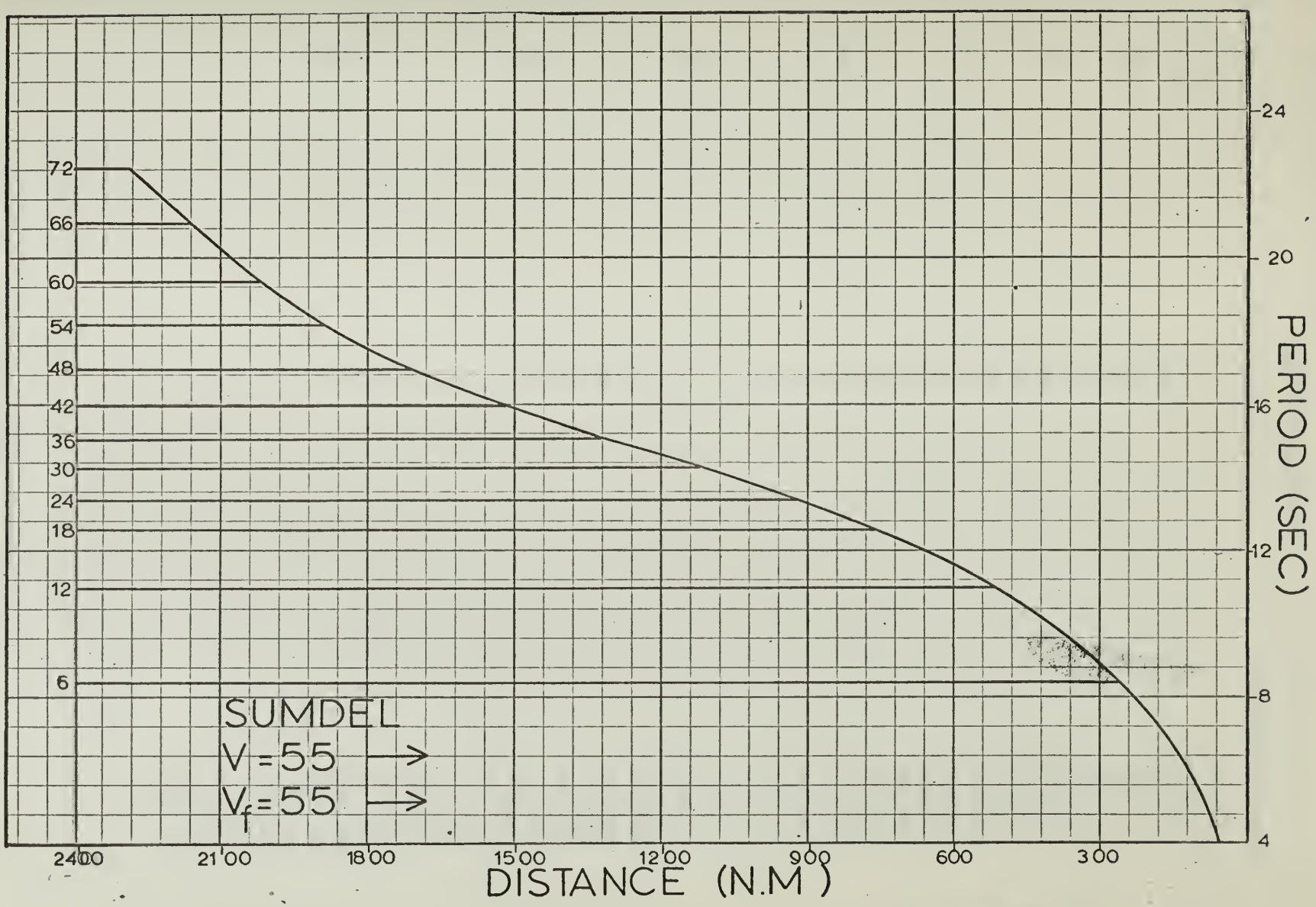

72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55 →
Vf = 50 →
2000
1750
1500
1250
1000
750
500
250
DISTANCE (N.M.)
24
20
16
12
8
4
PERIOD (SEC)




LAG
V = 55
V_f = 55
72
66
60
54
48
42
36
30
24
18
12
6
3600
3150
2700
2250
1800
1350
900
450
DISTANCE (N.M.)
4
8
12
16
20
24
PERIOD (SEC)


PERIOD (SEC)
24
20
16
12
8
4
72
66
60
54
48
42
36
30
24
18
12
6
FOPRIME
V = 55 →
Vf = 55 →
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

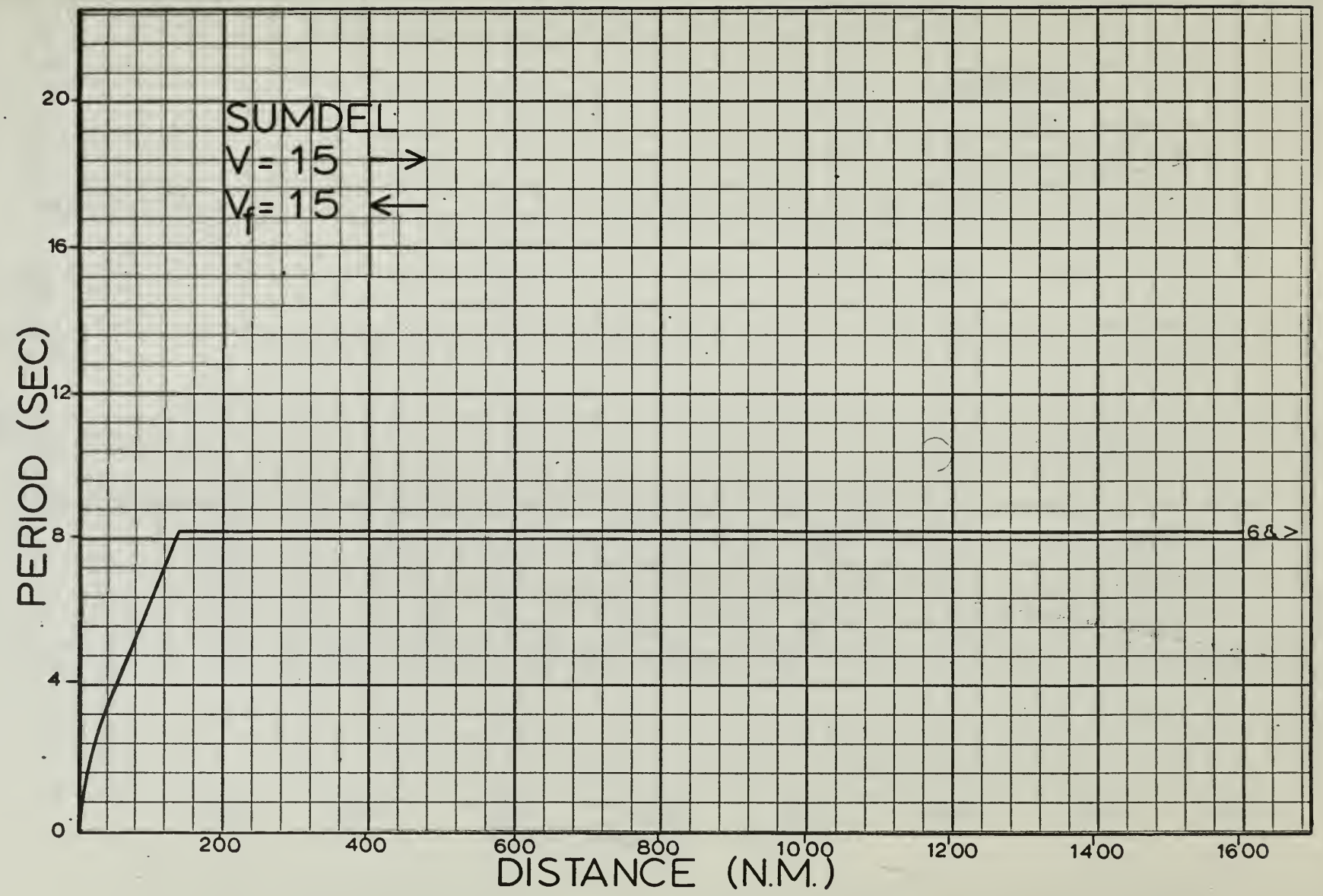



72
66
60
54
48
42
36
30
24
18
12
6
SUMDEL
V = 55
V_f = 55
2400
2100
1800
1500
1200
900
600
300
DISTANCE (N.M)
24
20
16
12
8
4
PERIOD (SEC)

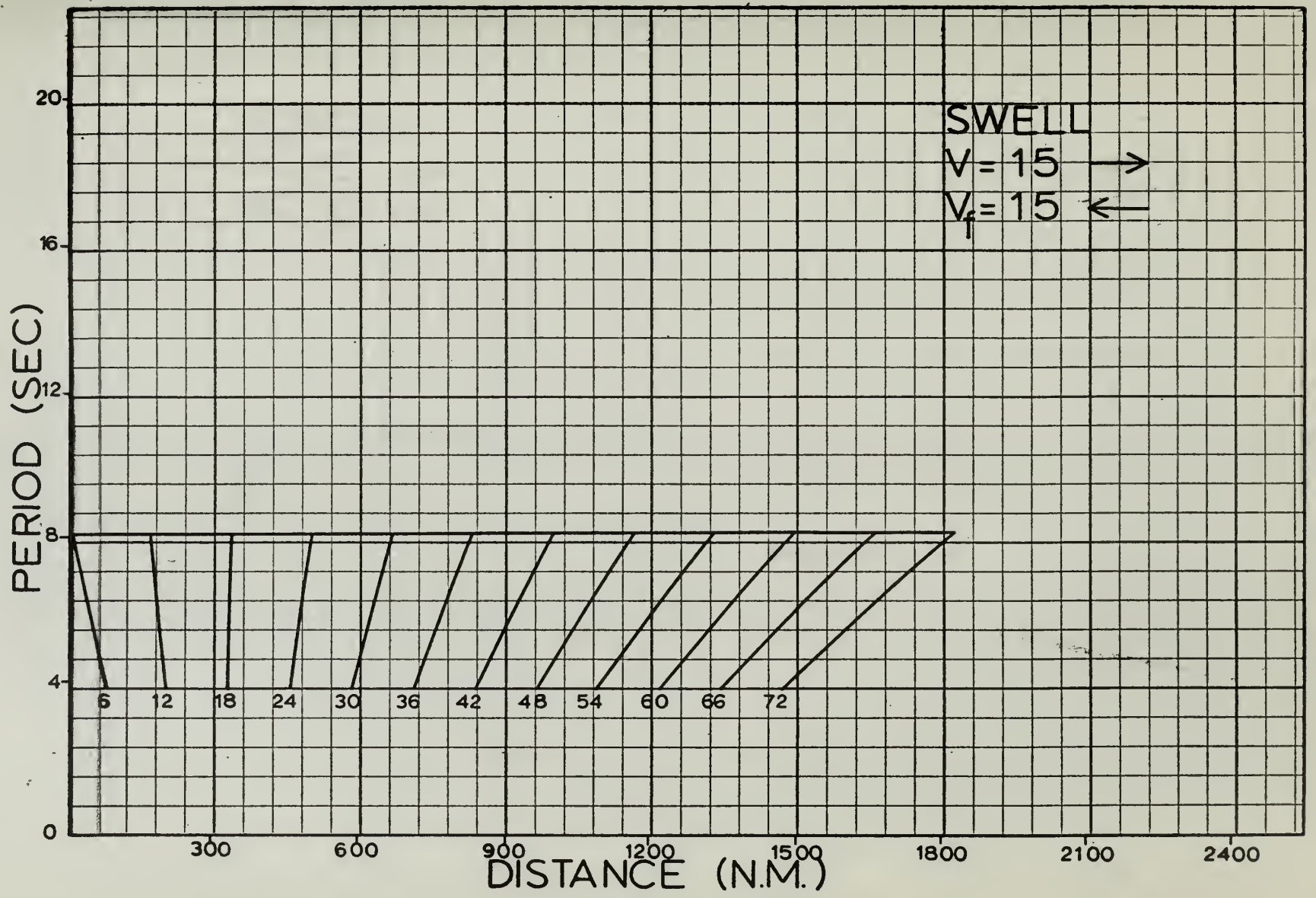
18.3 Moving (windward) Fetch Model Graphs

INDEX OF GRAPHS

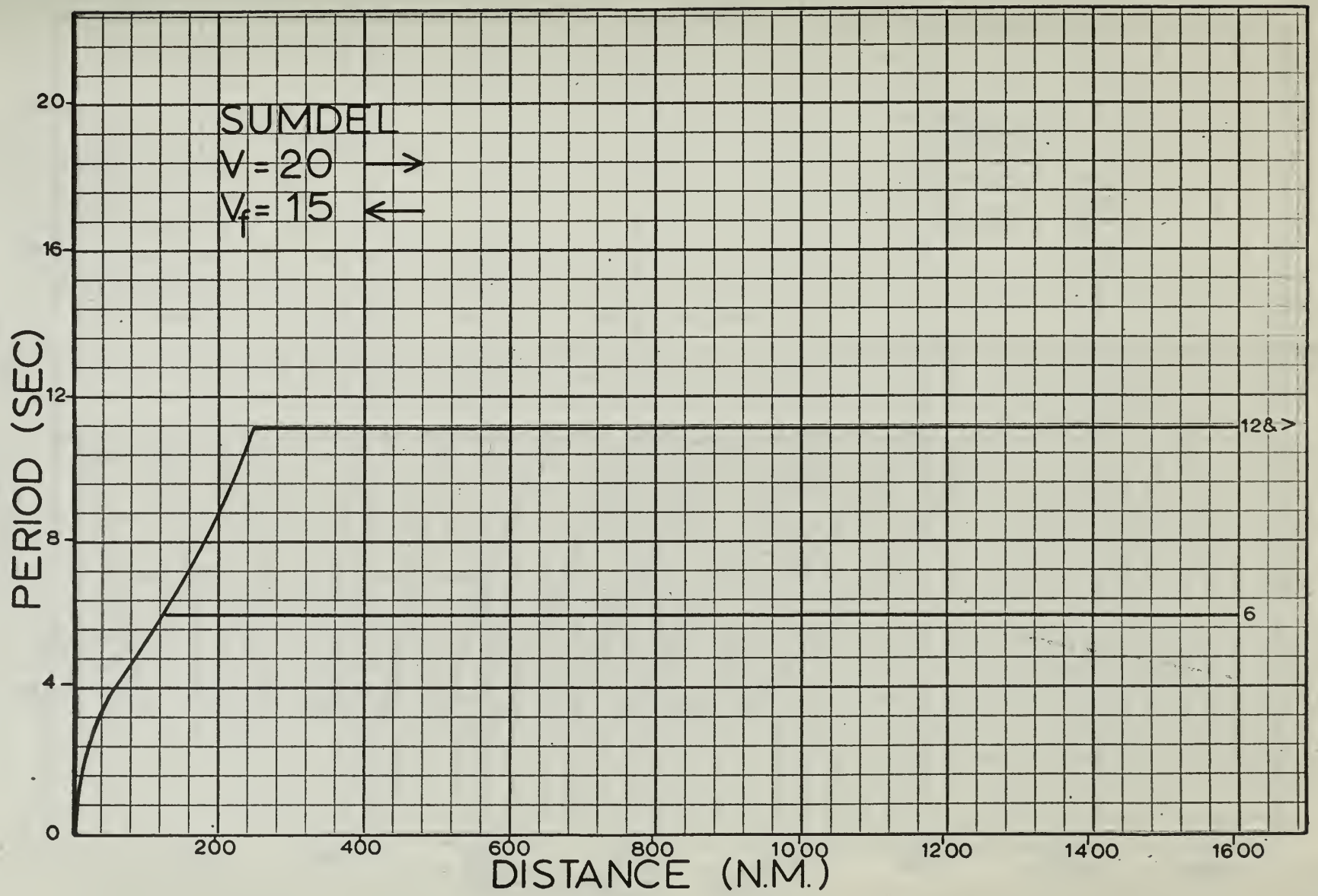
Wind Speed (V)	Fetch Speed (V_f)	Inclusive Pages
15	15	214-215
20	15	216-217
	20	218-219
25	15	220-221
	20	222-223
	25	223-225
30	15	226-227
	20	228-229
	25	230-231
	30	232-233
35	15	234-235
	20	236-237
	25	238-239
	30	240-241
	35	242-243
40	15	244-245
	20	246-247
	25	248-249
	30	250-251
	35	252-253
	40	254-255
45	15	256-257
	20	258-259
	25	260-261
	30	262-263
	35	264-265
	40	266-267
	45	268-269
50	15	270-271
	20	272-273
	25	274-275
	30	276-277
	35	278-279
	40	280-281
	45	282-283
	50	284-285
55	15	286-287
	20	288-289
	25	290-291
	30	292-293
	35	294-295
	40	296-297
	45	298-299
	50	300-301
	55	302-303


SUMDEL
V = 15 →
Vf = 15 ←
20
16
12
8
4
0
PERIOD (SEC)
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
68 >
214




SWELL
V = 15 →
Vf = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
300
600
900
1200
1500
1800
2100
2400
DISTANCE (N.M.)

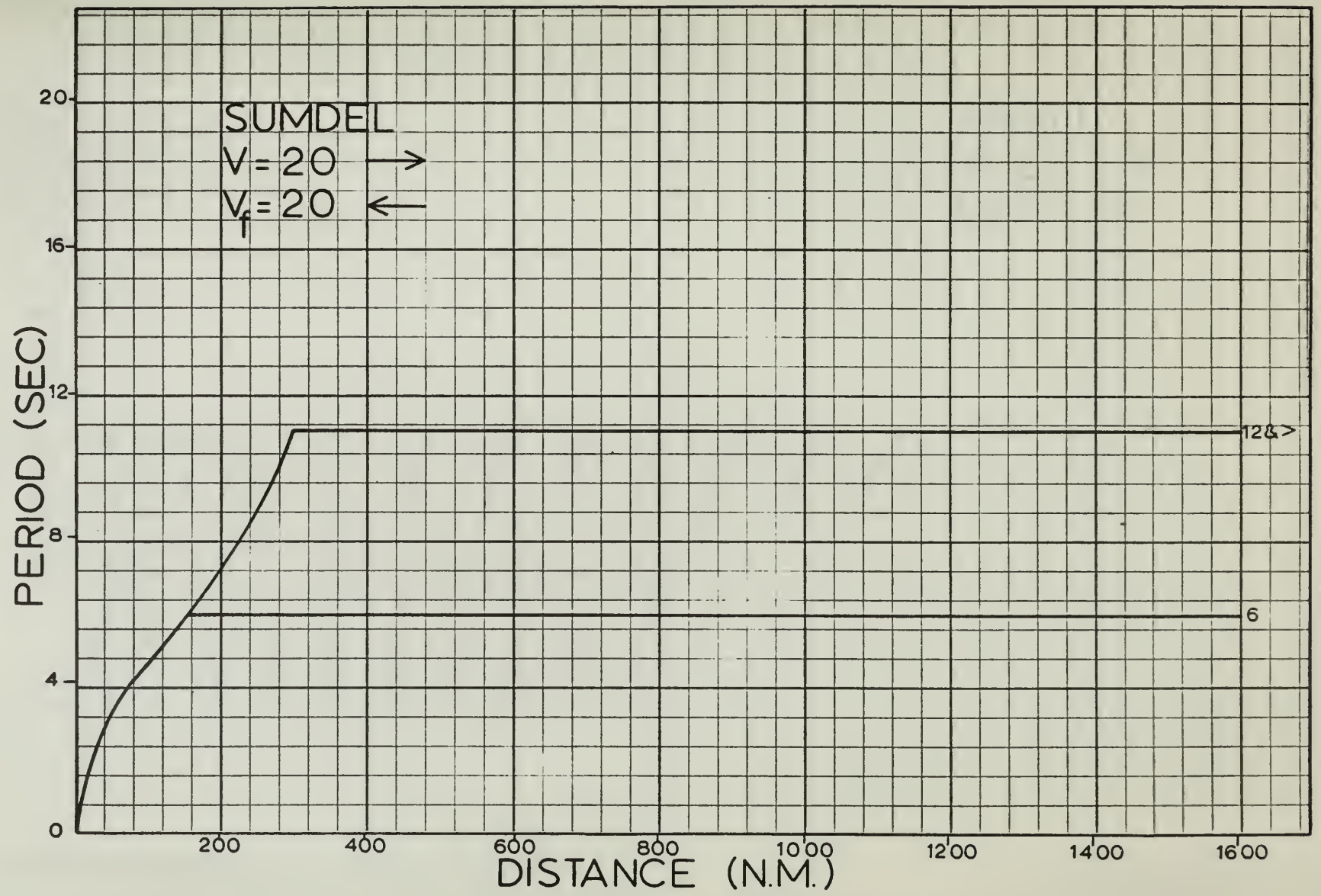



SUMDEL
V = 20 →
V_f = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
12&>
6

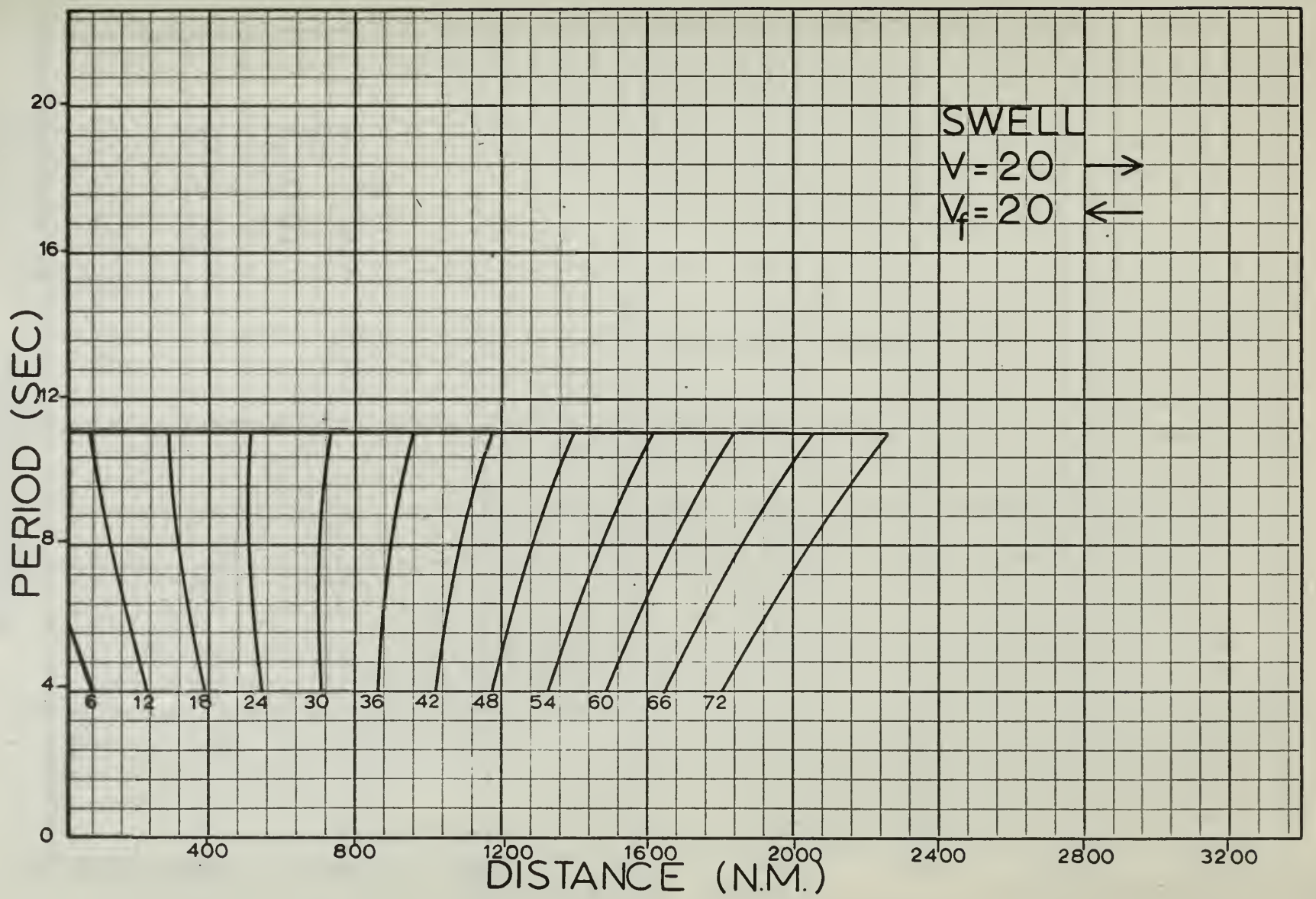



SWELL
V = 20 →
Vf = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
300
600
900
1200
1500
1800
2100
2400
DISTANCE (N.M.)

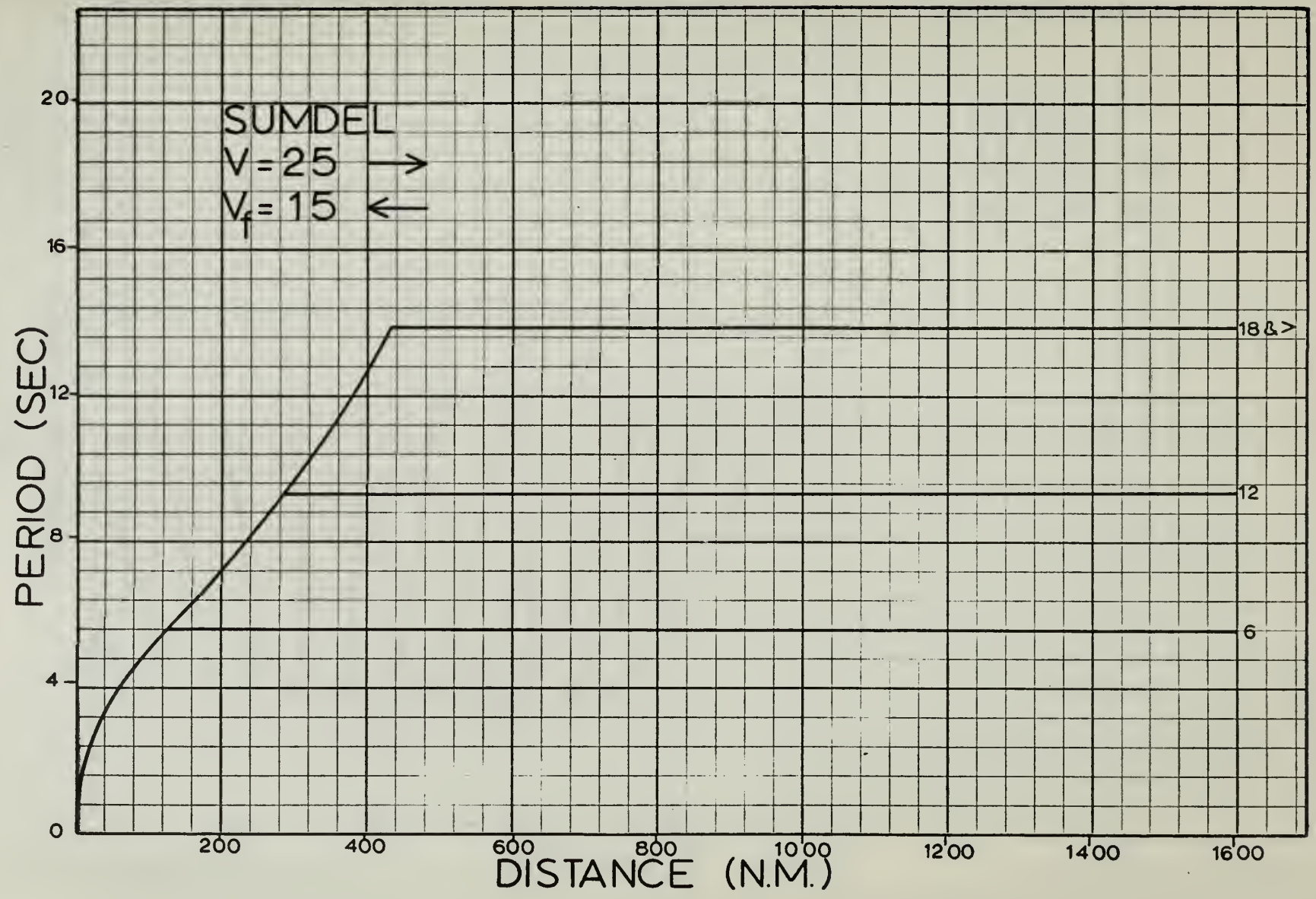



SUMDEL
V = 20 →
V_f = 20 ←
20
16
12
8
4
0
PERIOD (SEC)
12&>
6
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

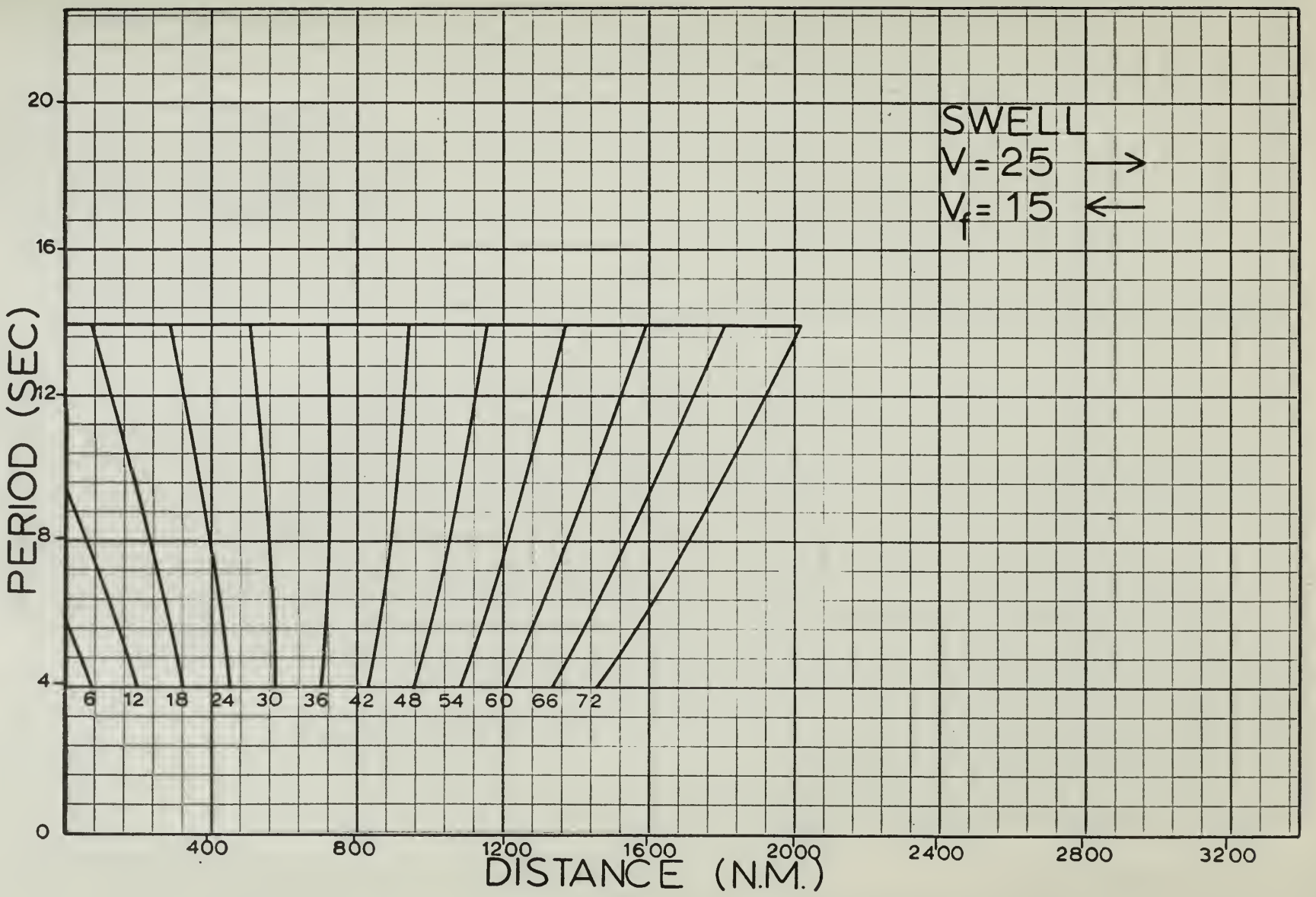



SWELL
V = 20 →
Vf = 20 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

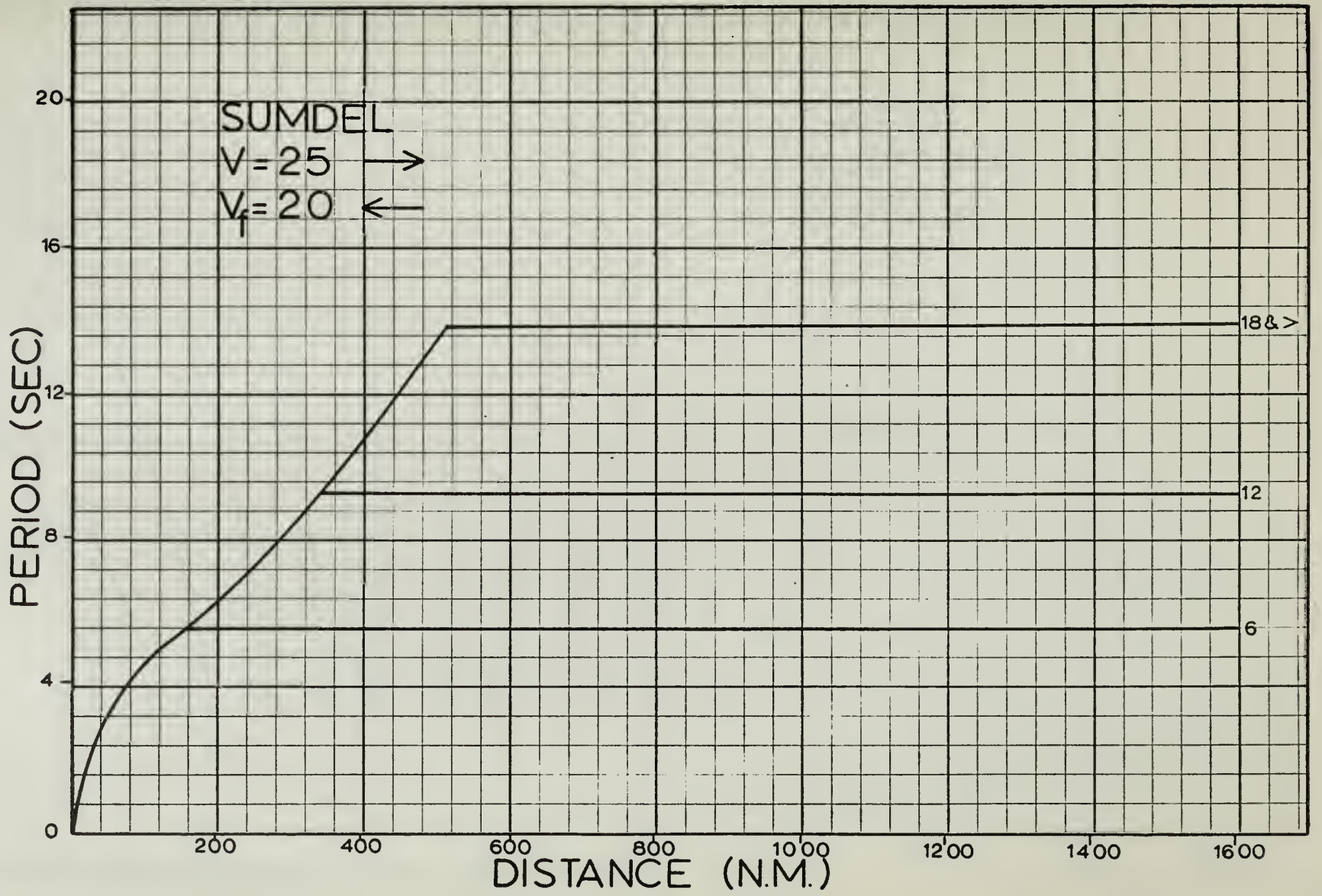



SUMDEL
V = 25
V_f = 15
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
18 &>
12
6

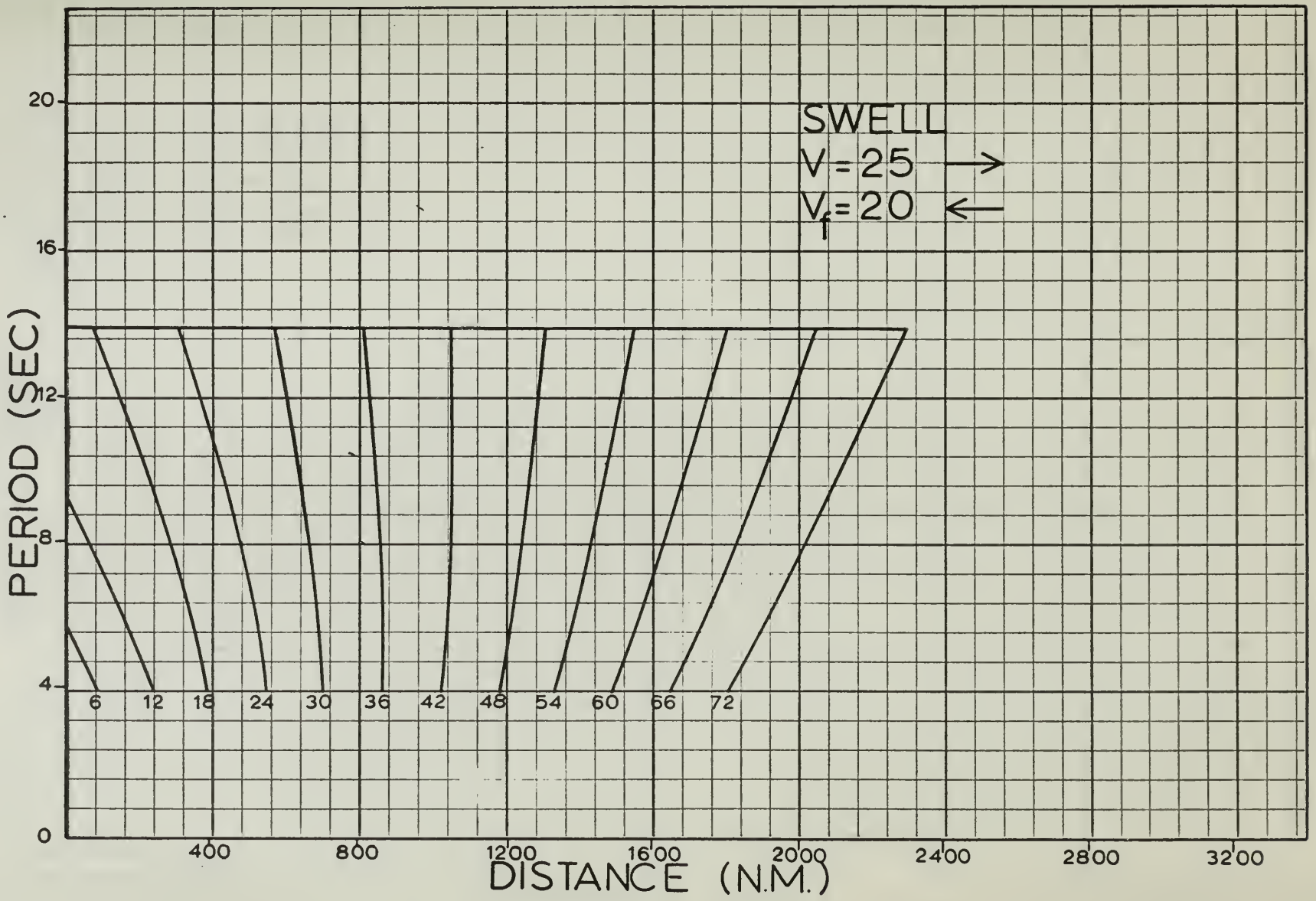



SWELL
V = 25 →
Vf = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)



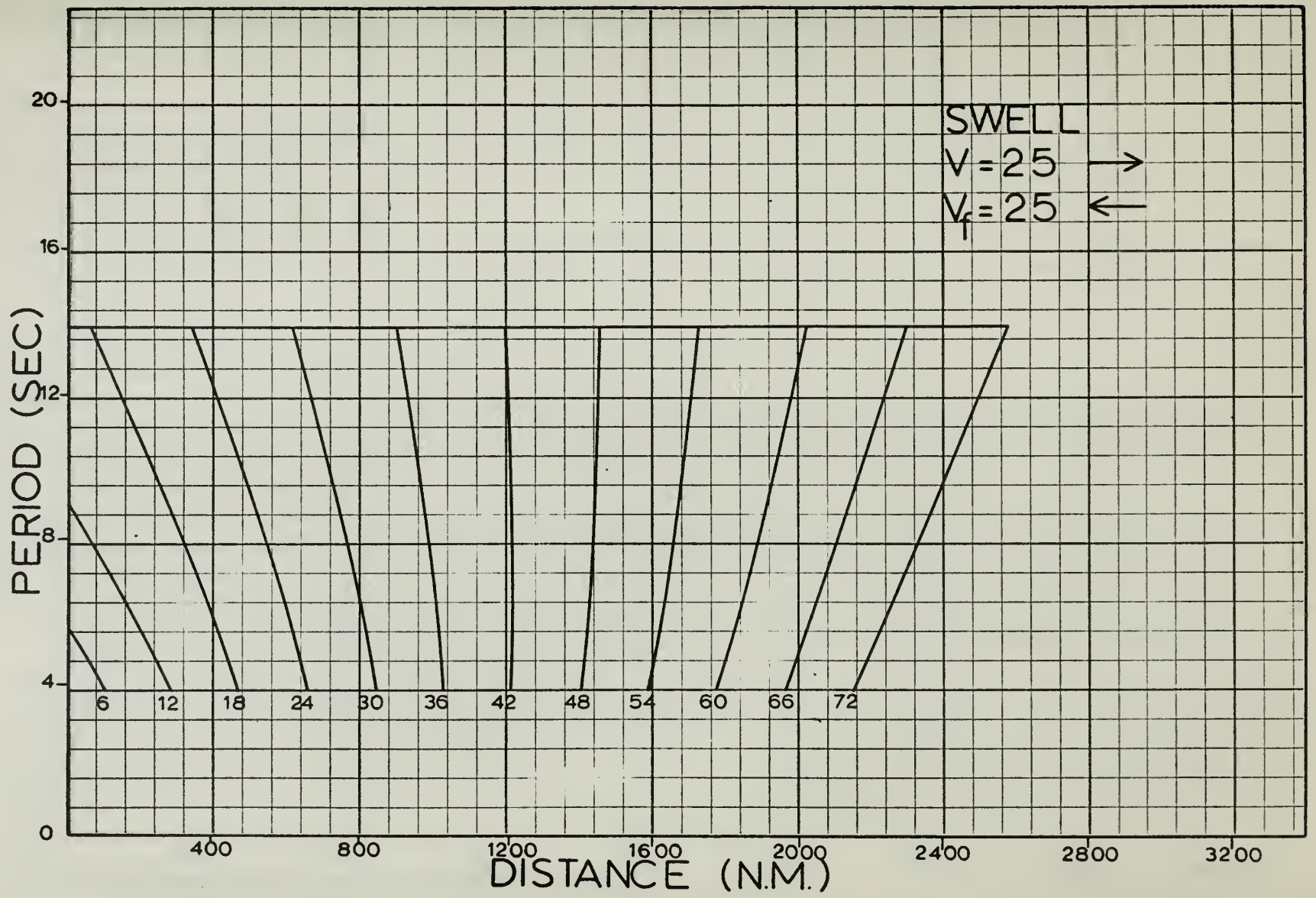

SUMDEL
V = 25
V_f = 20
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
18 & >
12
6



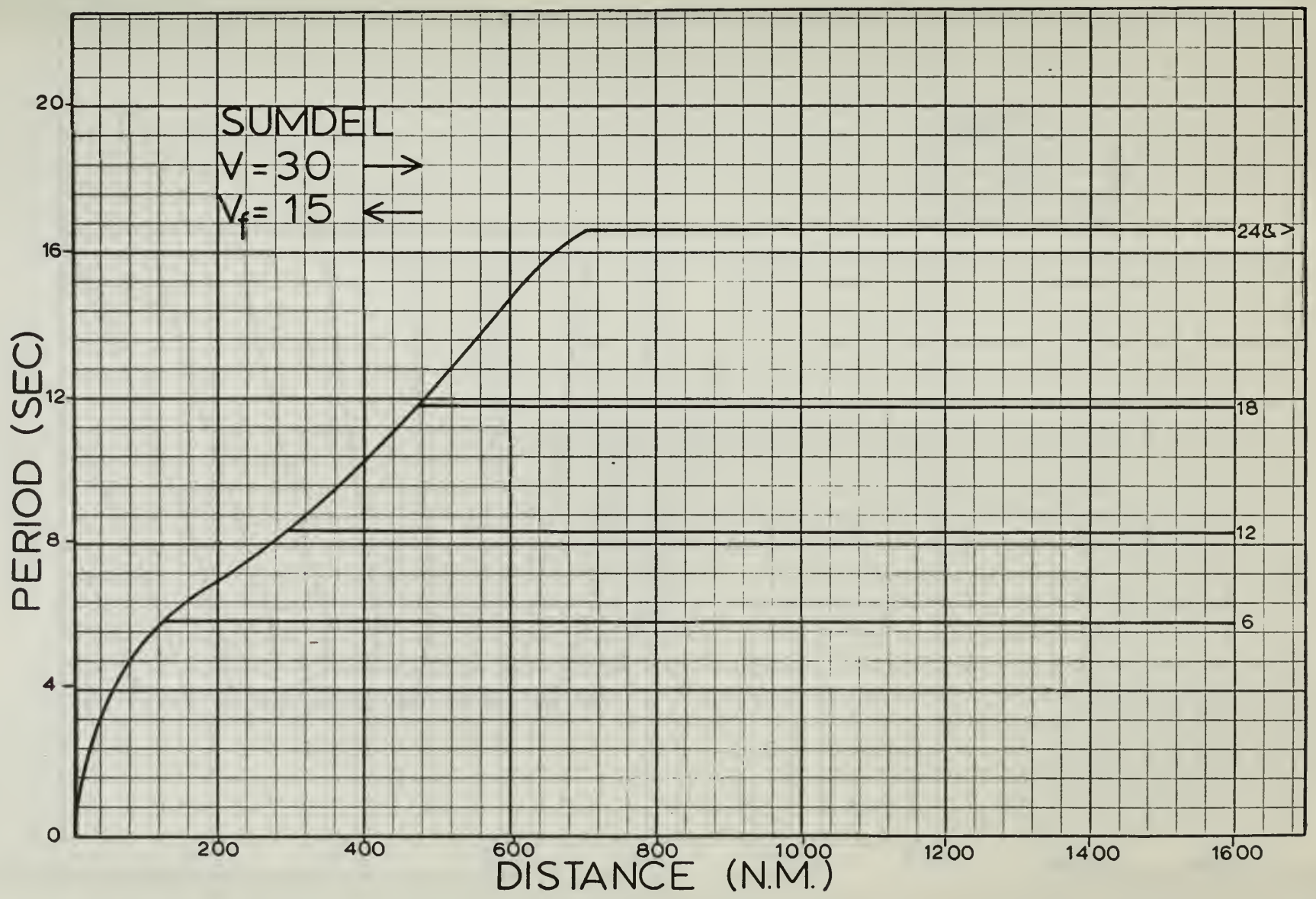

SWELL
V = 25
V_f = 20
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)


SUMDEL
V = 25 →
Vf = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
18& >
12
6

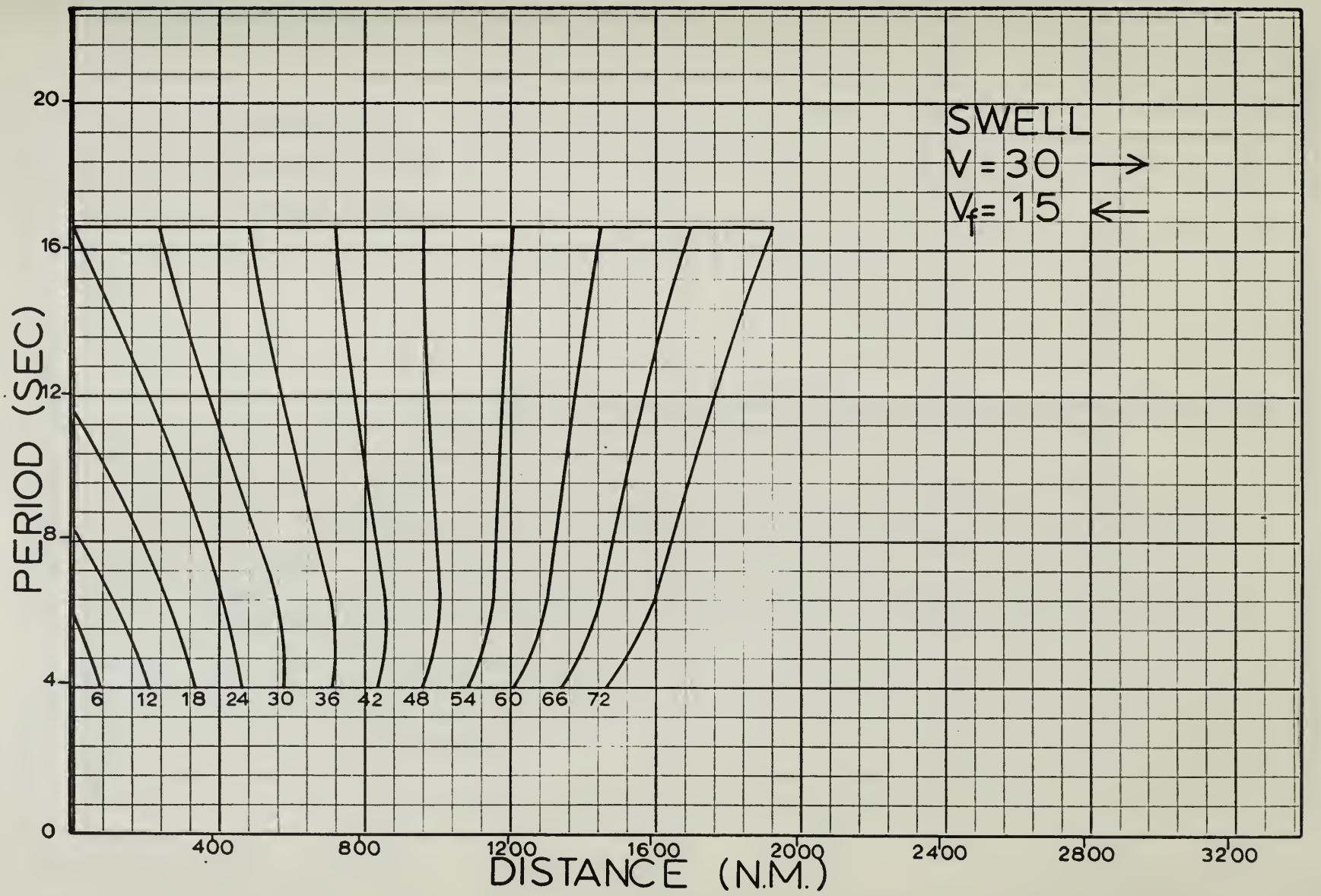



SWELL
V = 25 →
Vf = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

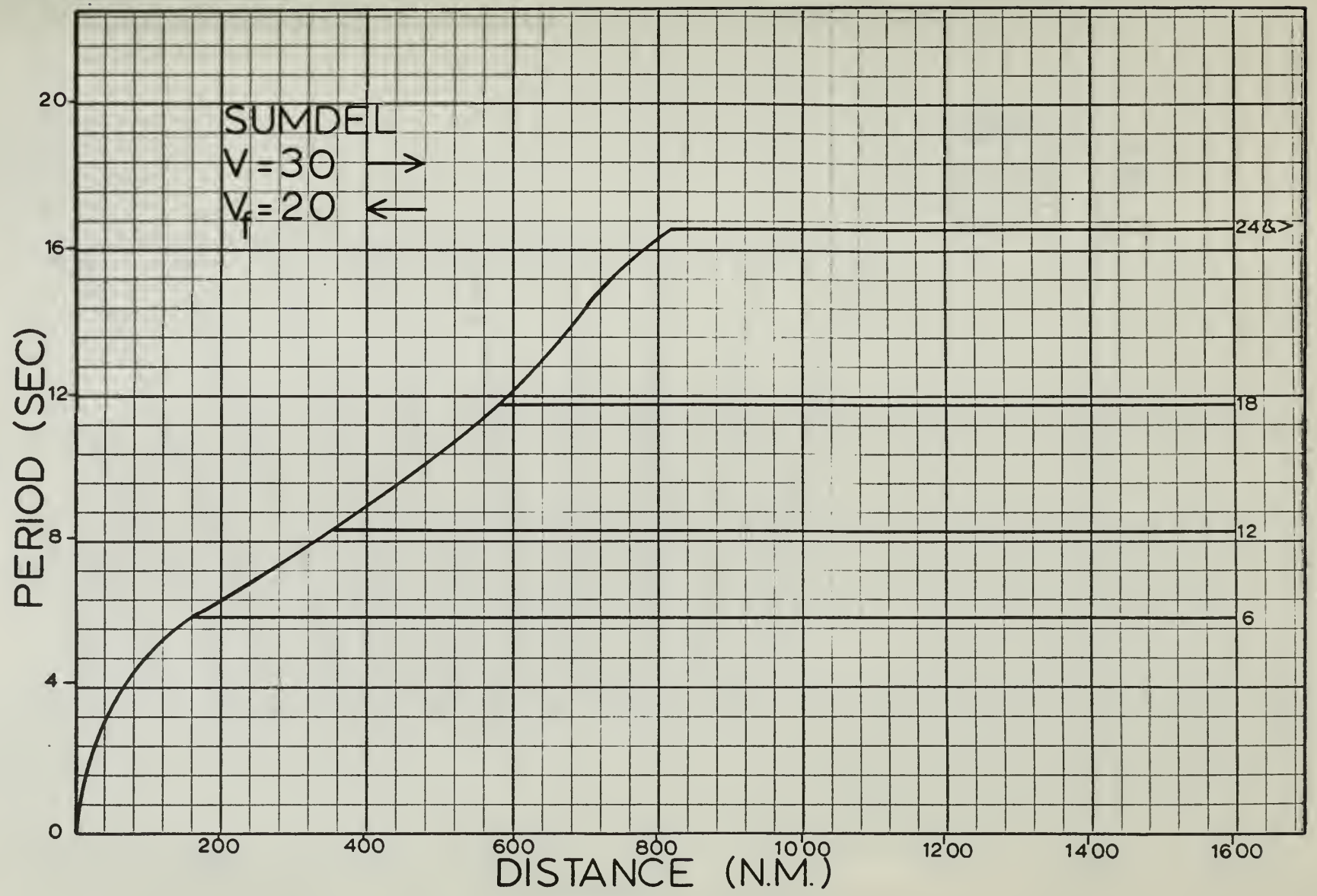



SUMDEL
V = 30 →
V_f = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
24&>
18
12
6

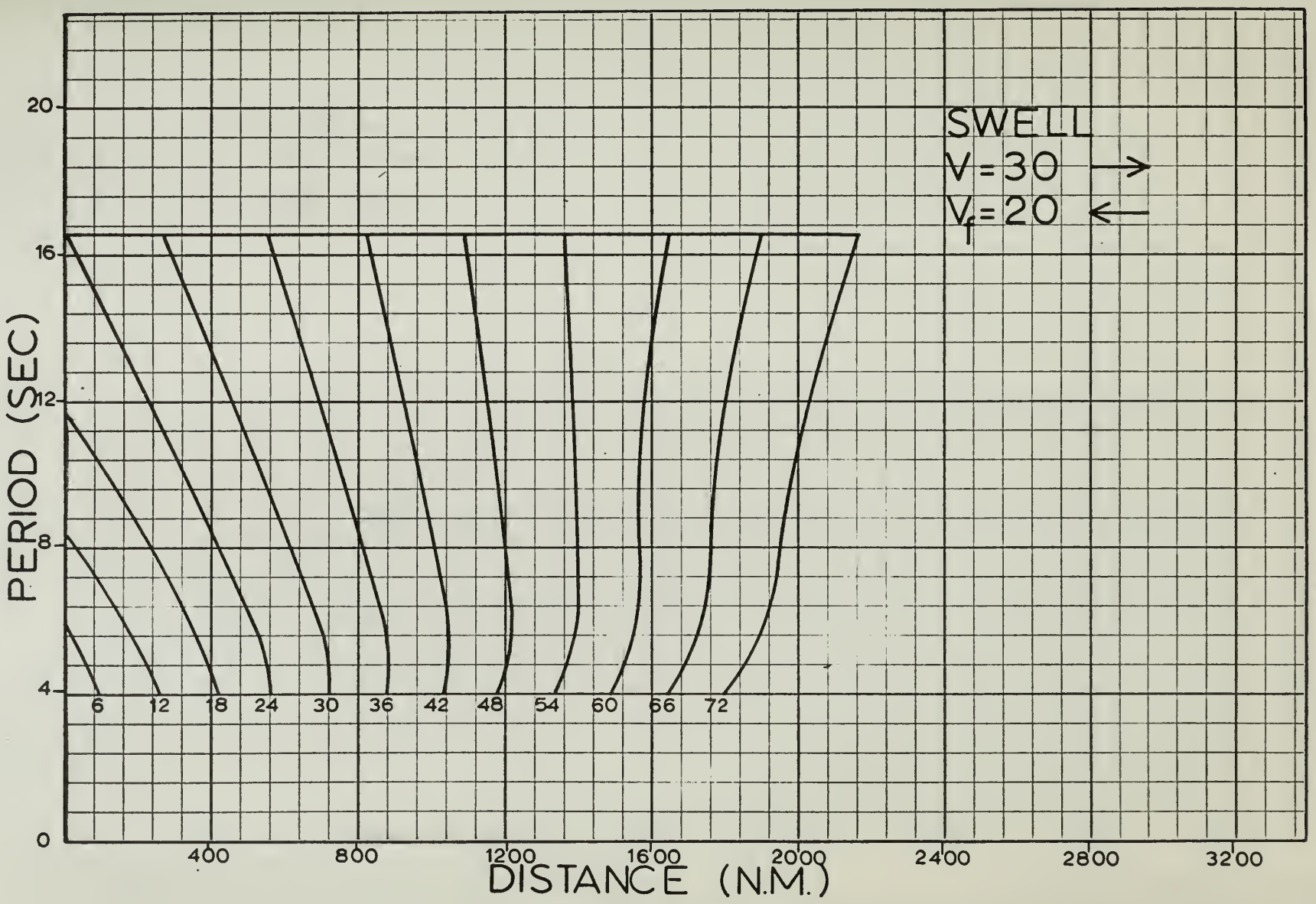



SWELL
V = 30 →
Vf = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

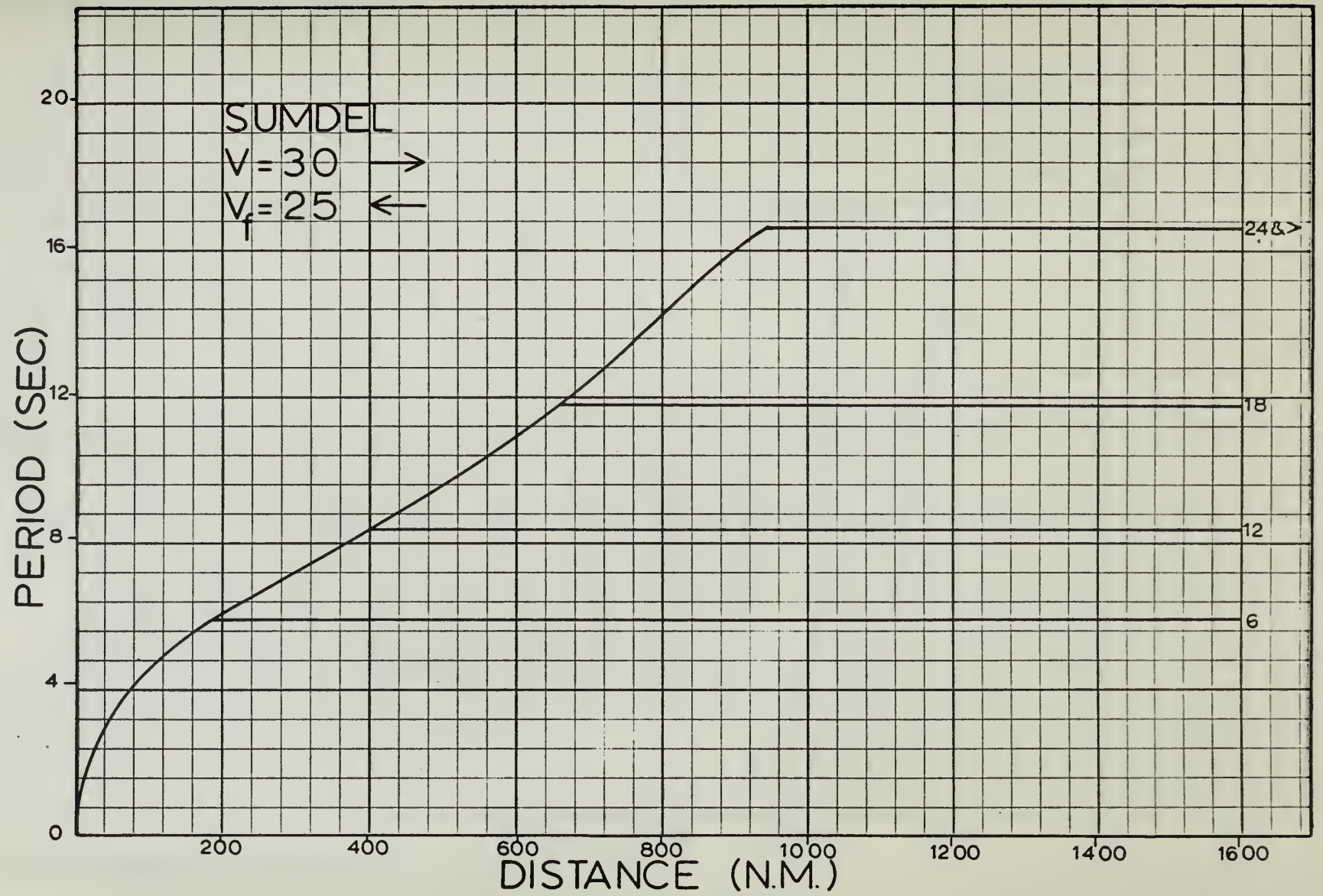



SUMDEL
V = 30
Vf = 20
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
24&>
18
12
6

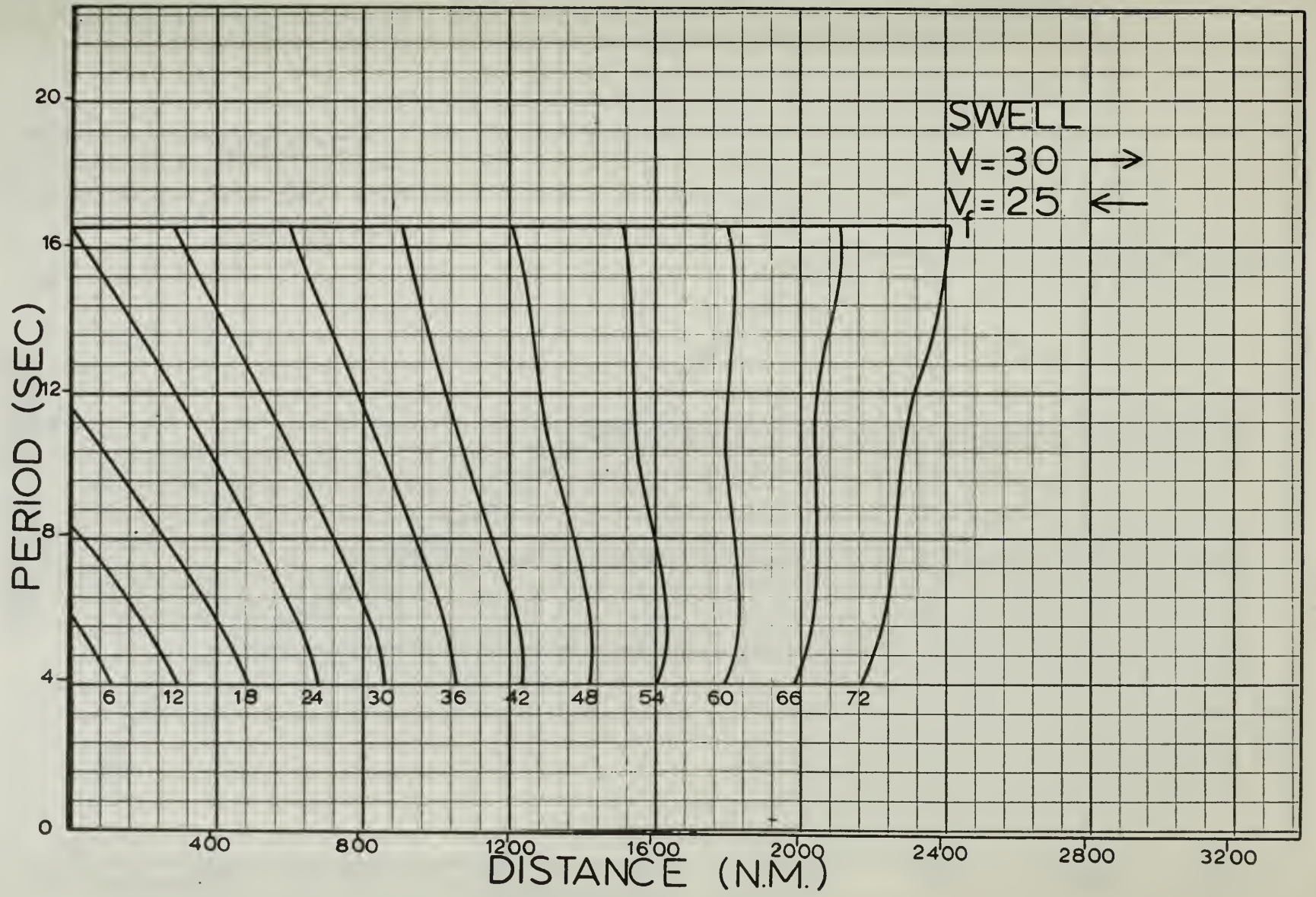



SWELL
V = 30 →
Vf = 20 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

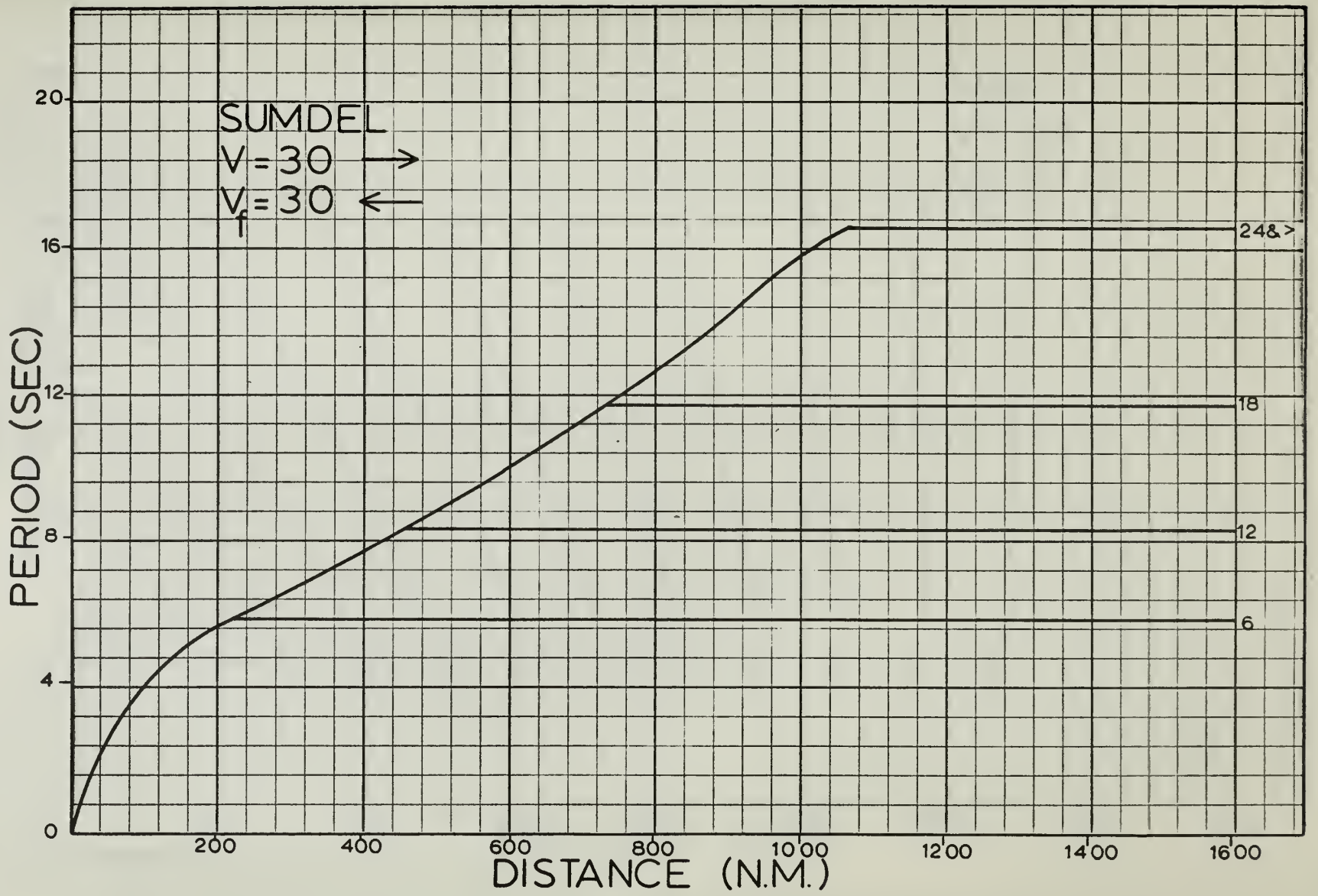



SUMDEL
V=30 →
V_f=25 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
24&>
18
12
6

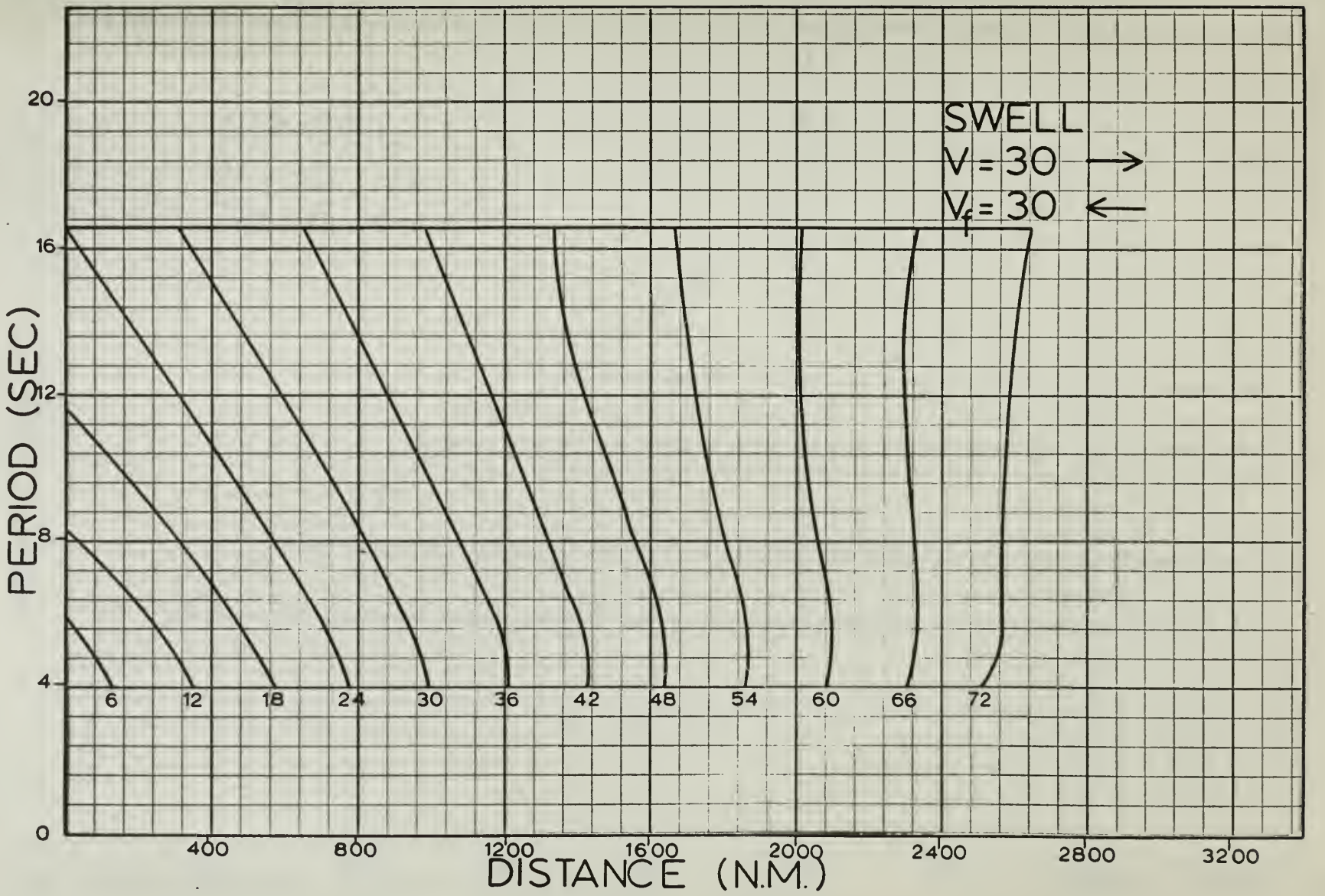



SWELL
V = 30 →
V_f = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

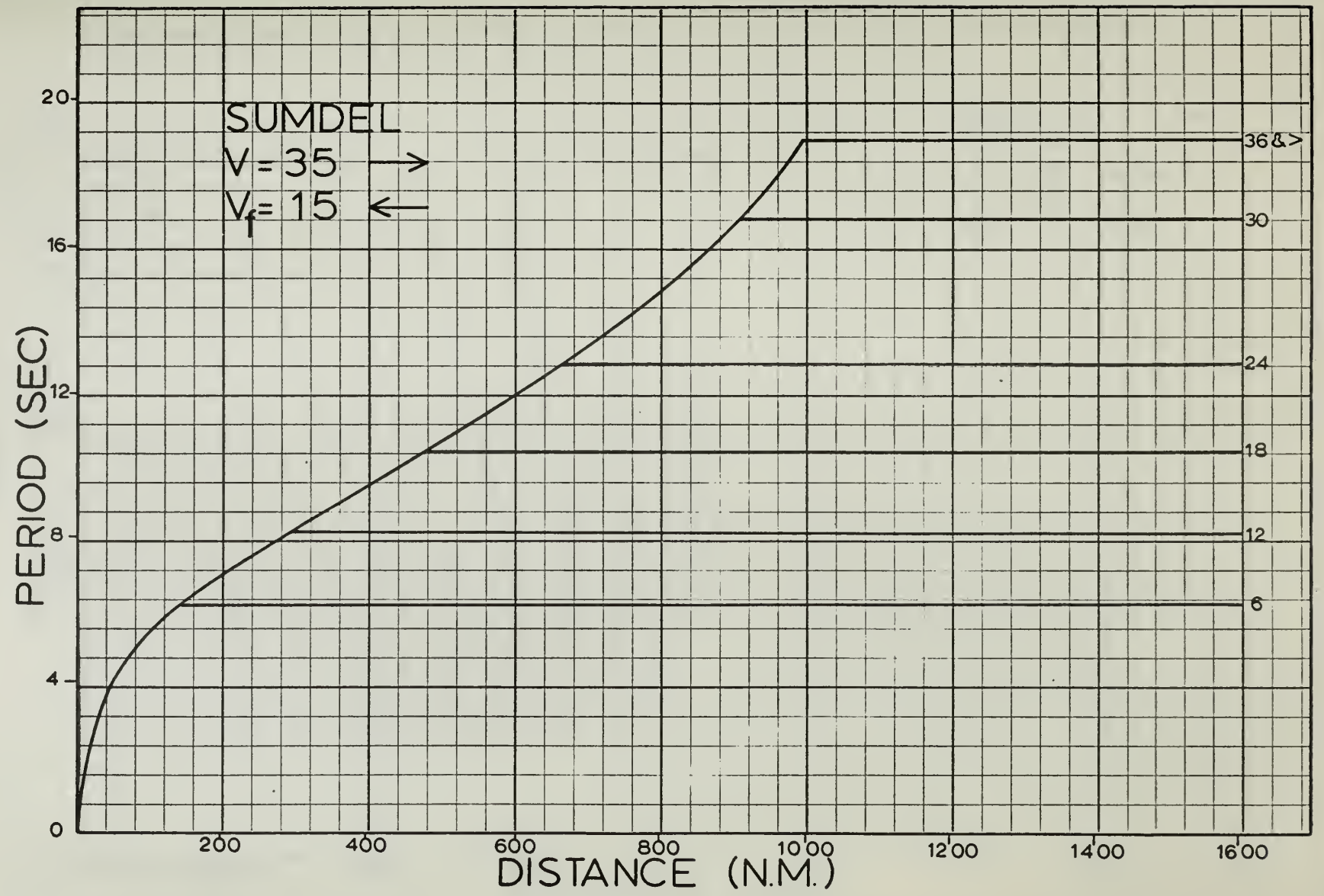



SUMDEL
V = 30 →
V_f = 30 ←
24&>
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

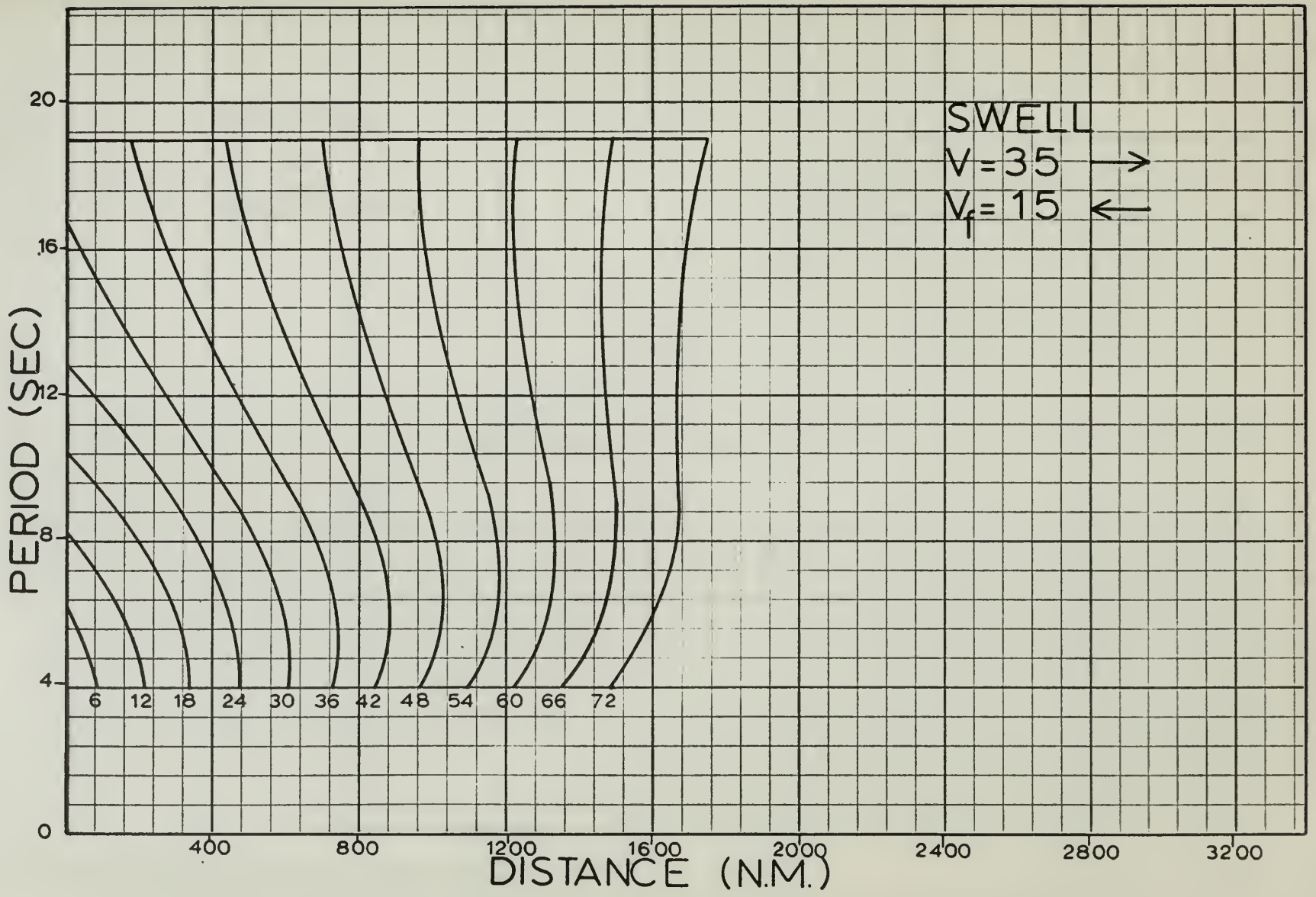



SWELL
V = 30 →
Vf = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

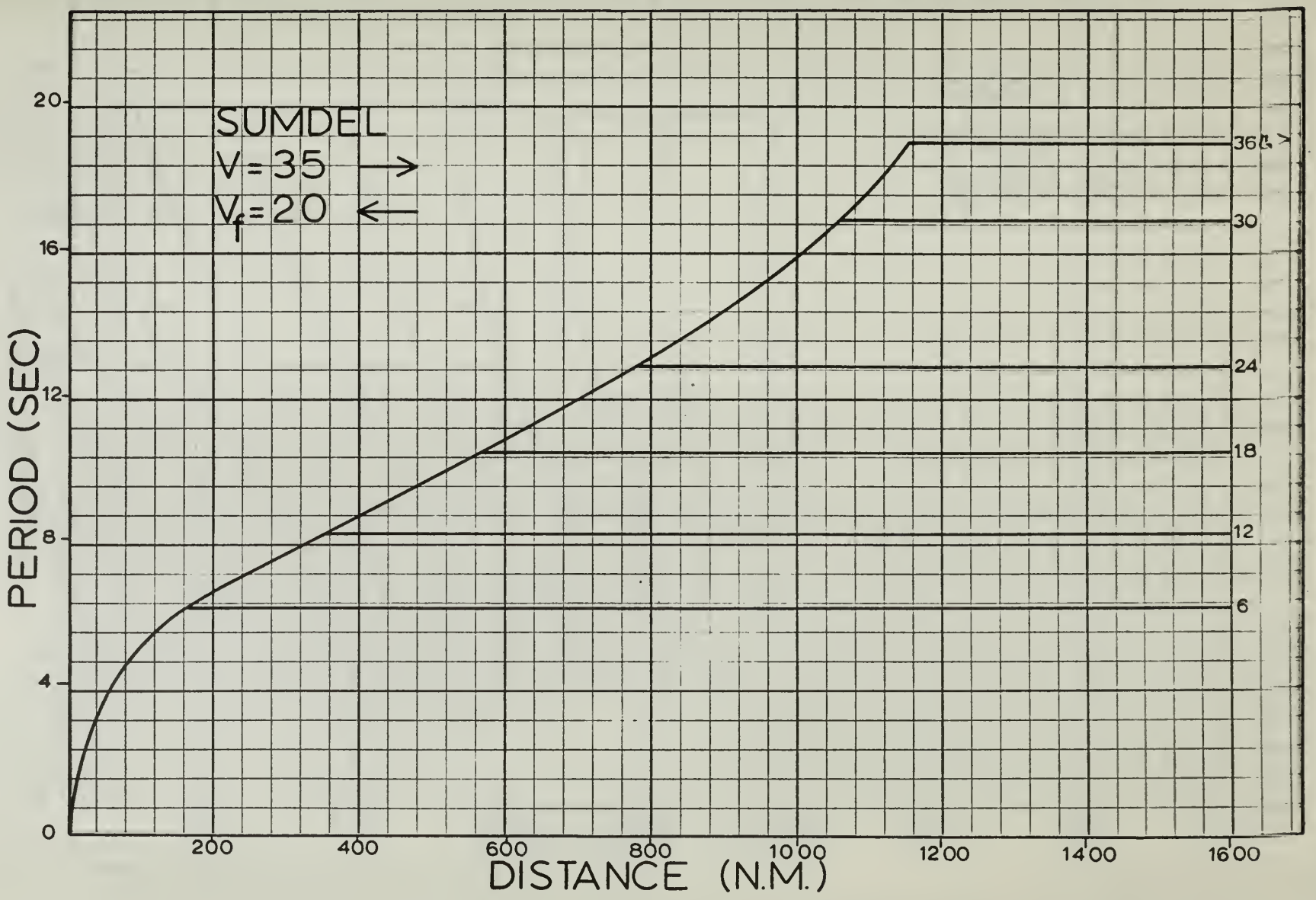



SUMDEL
V = 35 →
Vf = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36 &>
30
24
18
12
6

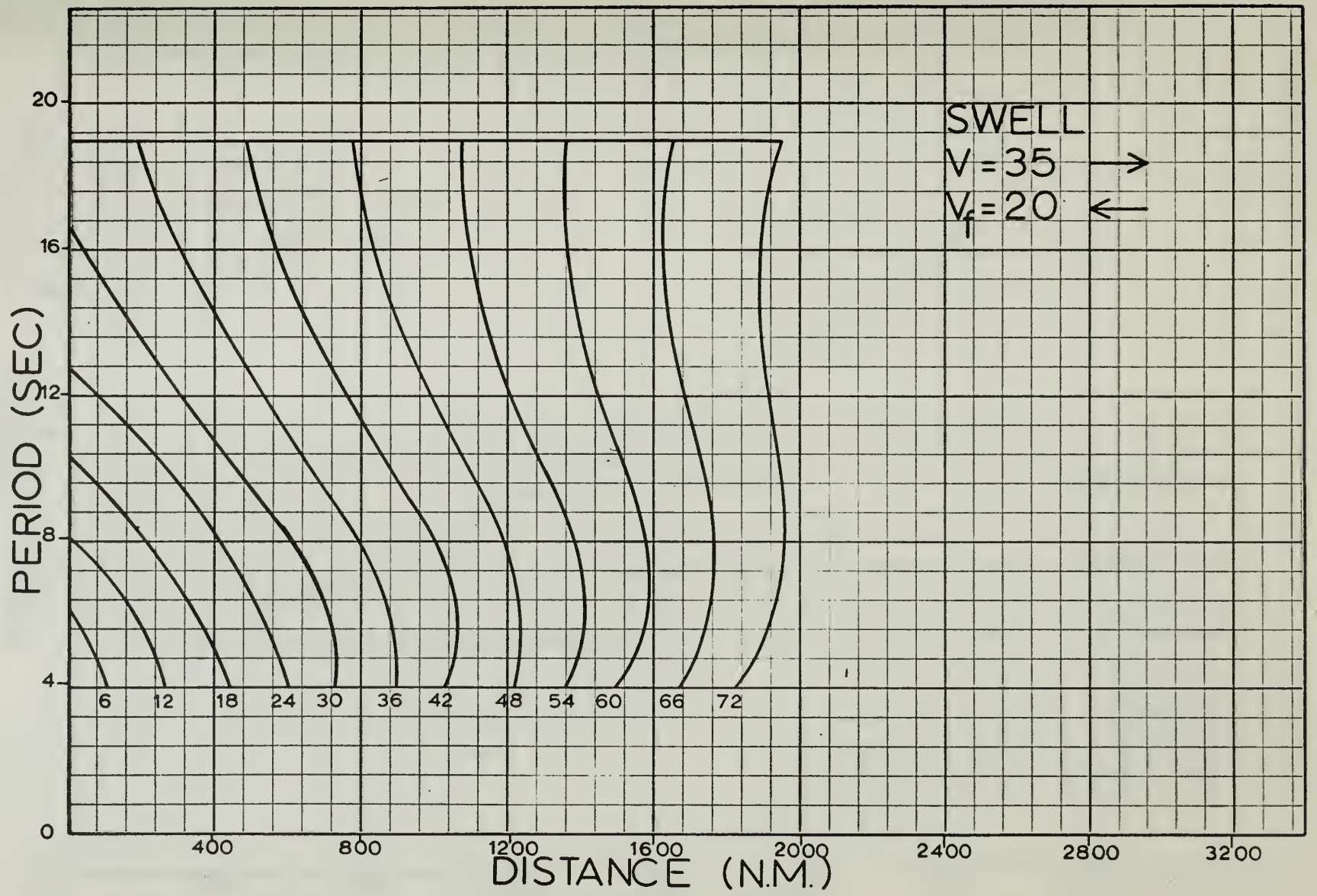



SWELL
V = 35 →
V_f = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

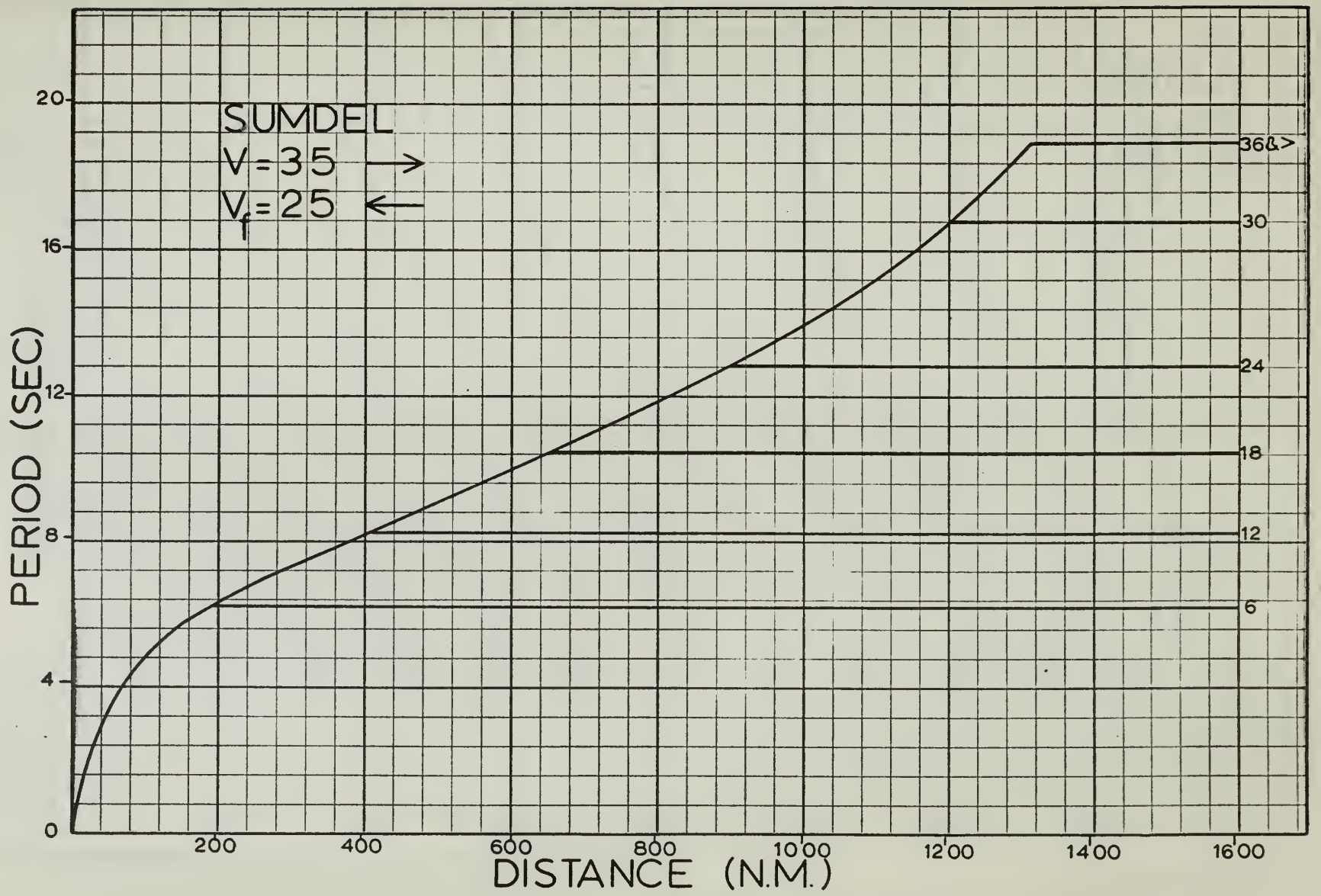



SUMDEL
V = 35
V_f = 20
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
360
30
24
18
12
6

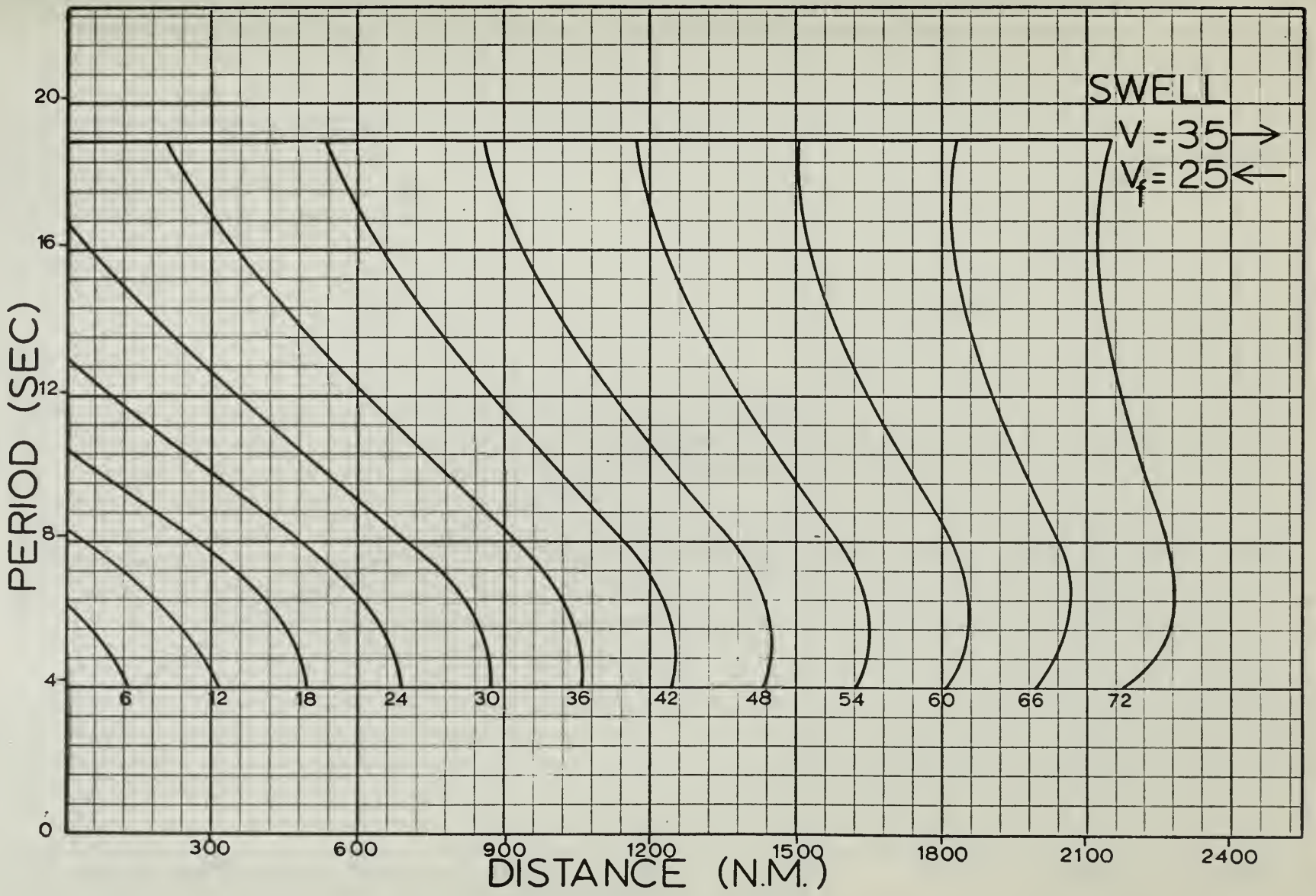



SWELL
V = 35
Vf = 20
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

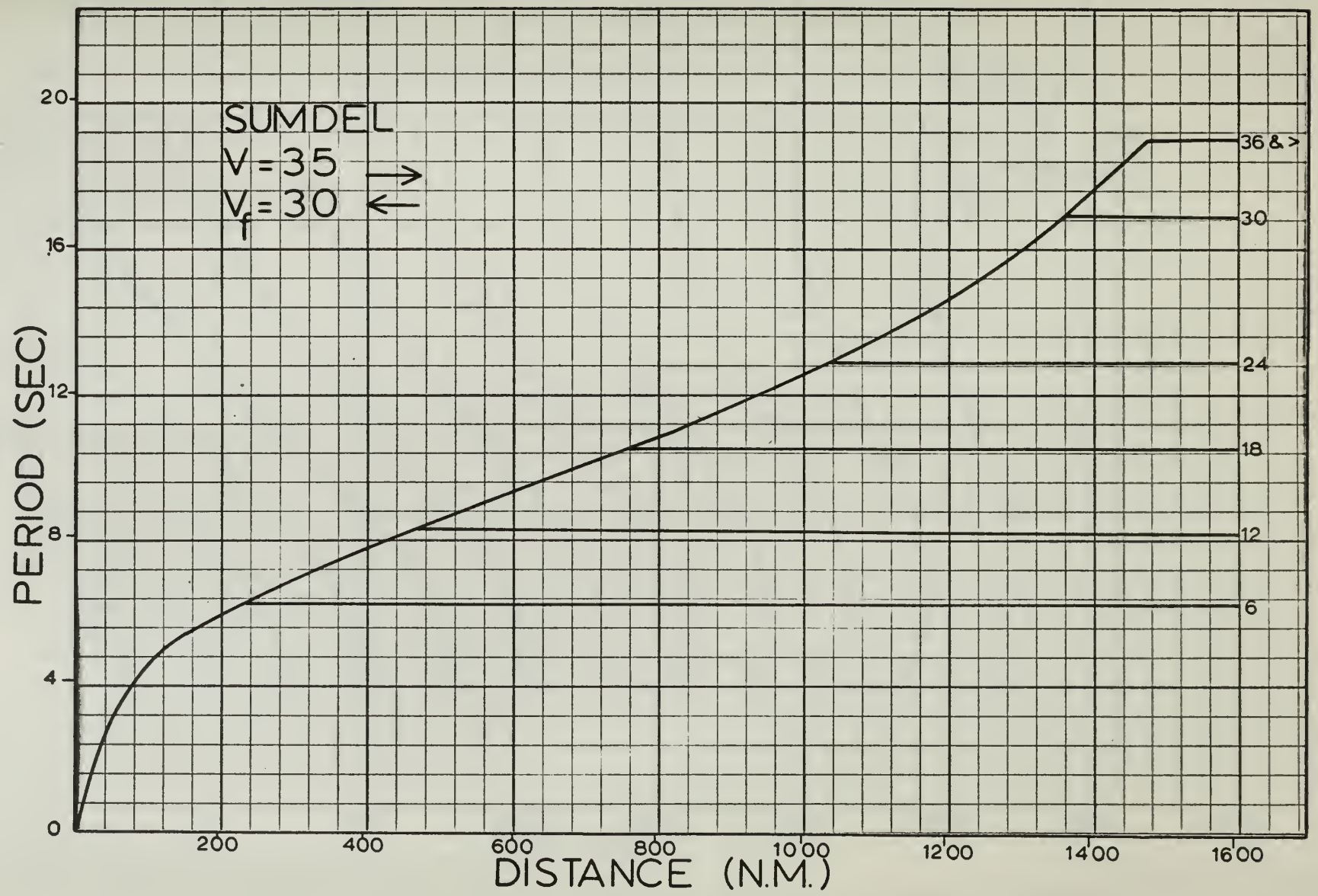



SUMDEL
V = 35 →
V_f = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36&>
30
24
18
12
6

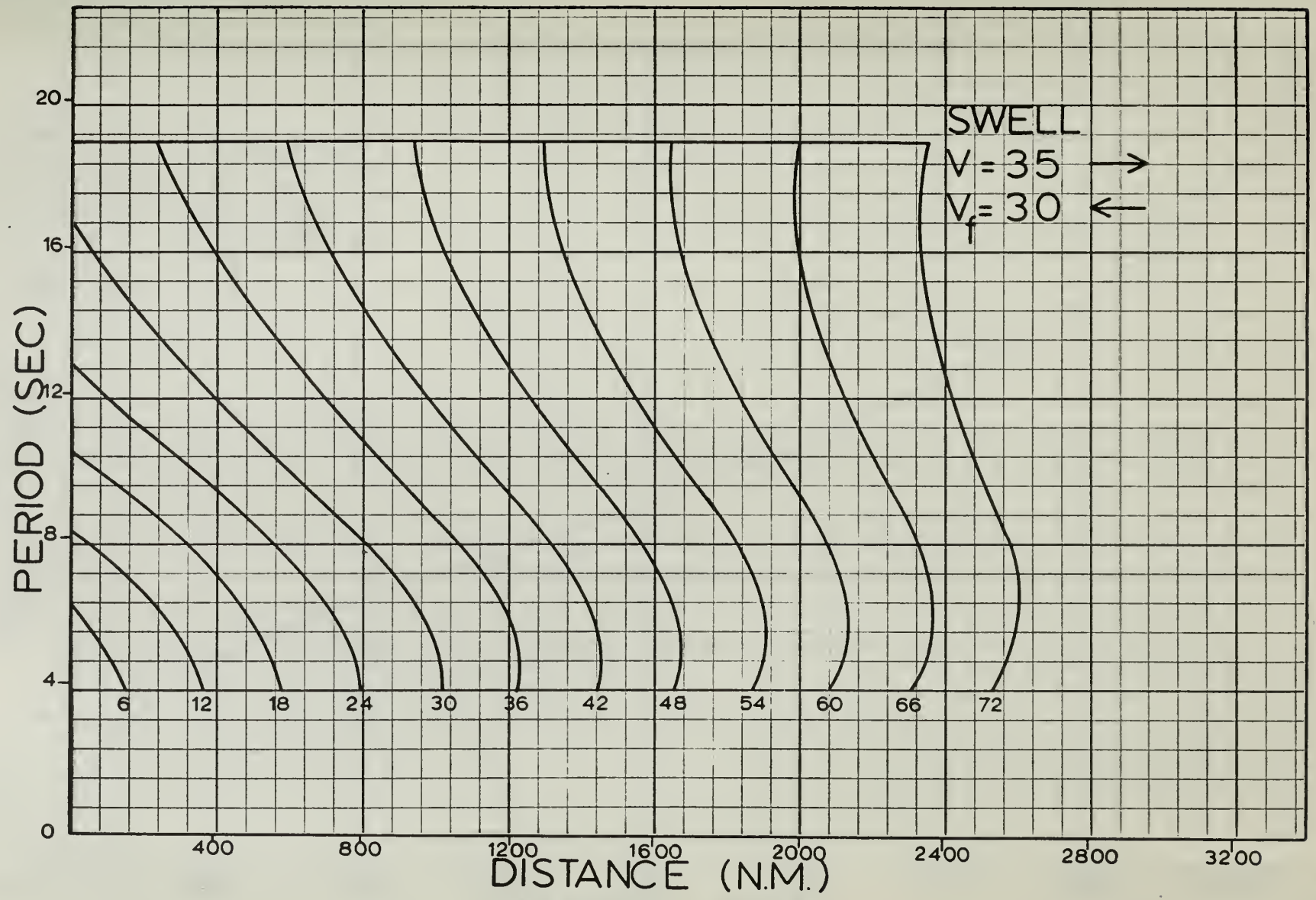



SWELL
V = 35 →
V_f = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
300
600
900
1200
1500
1800
2100
2400
DISTANCE (N.M.)

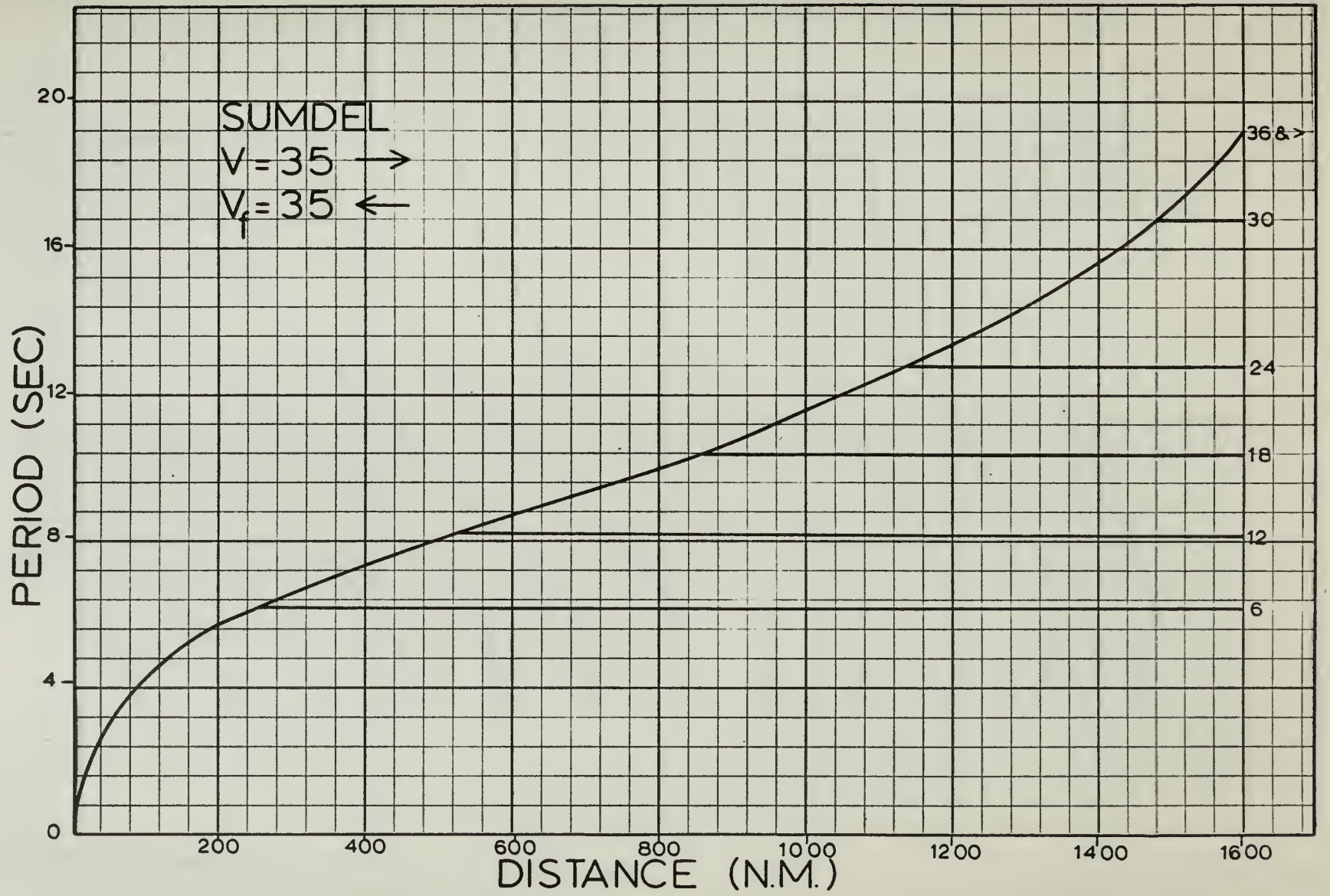



SUMDEL
V = 35
V_f = 30
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36 & >
30
24
18
12
6

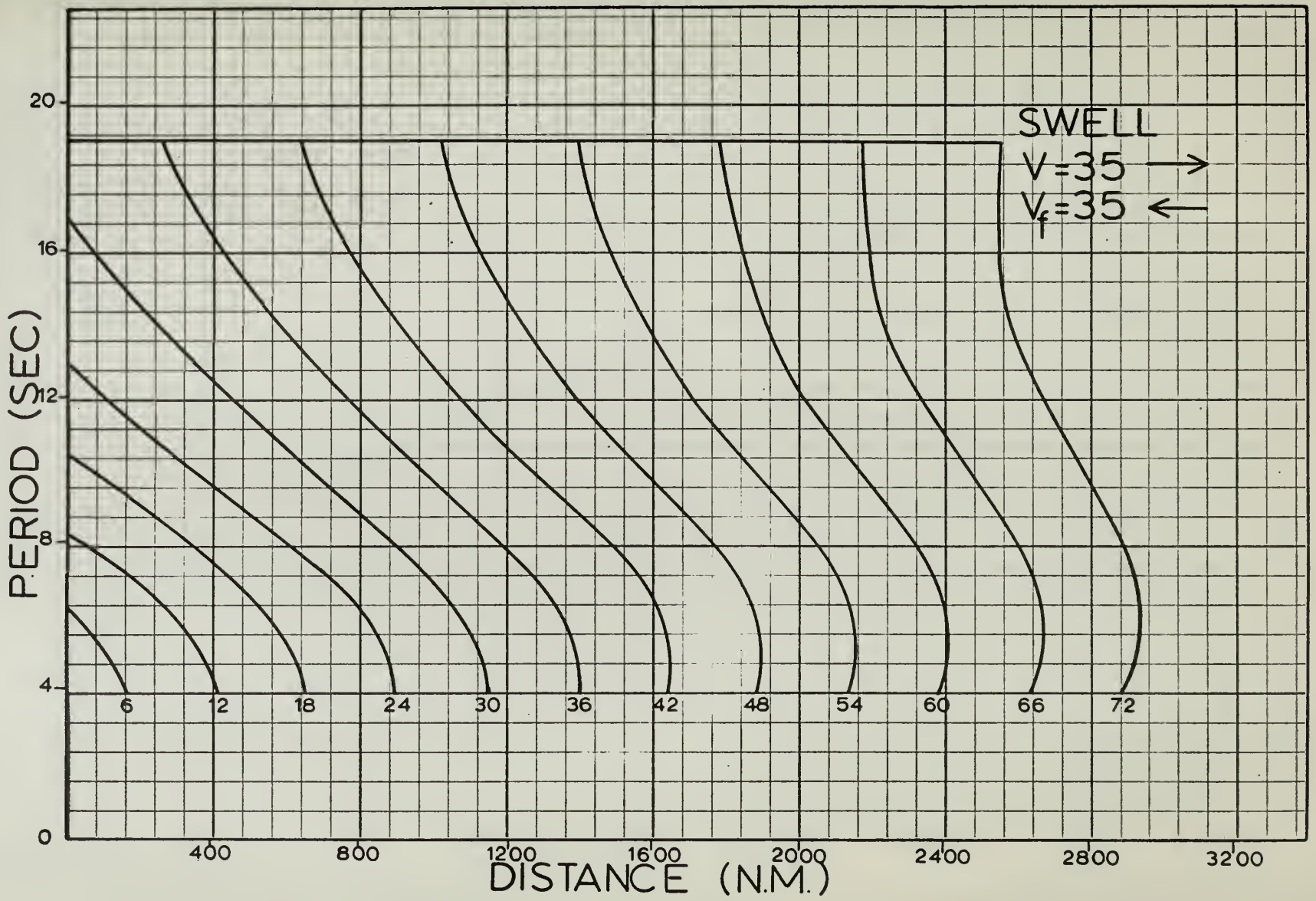



SWELL
V = 35 →
V_f = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

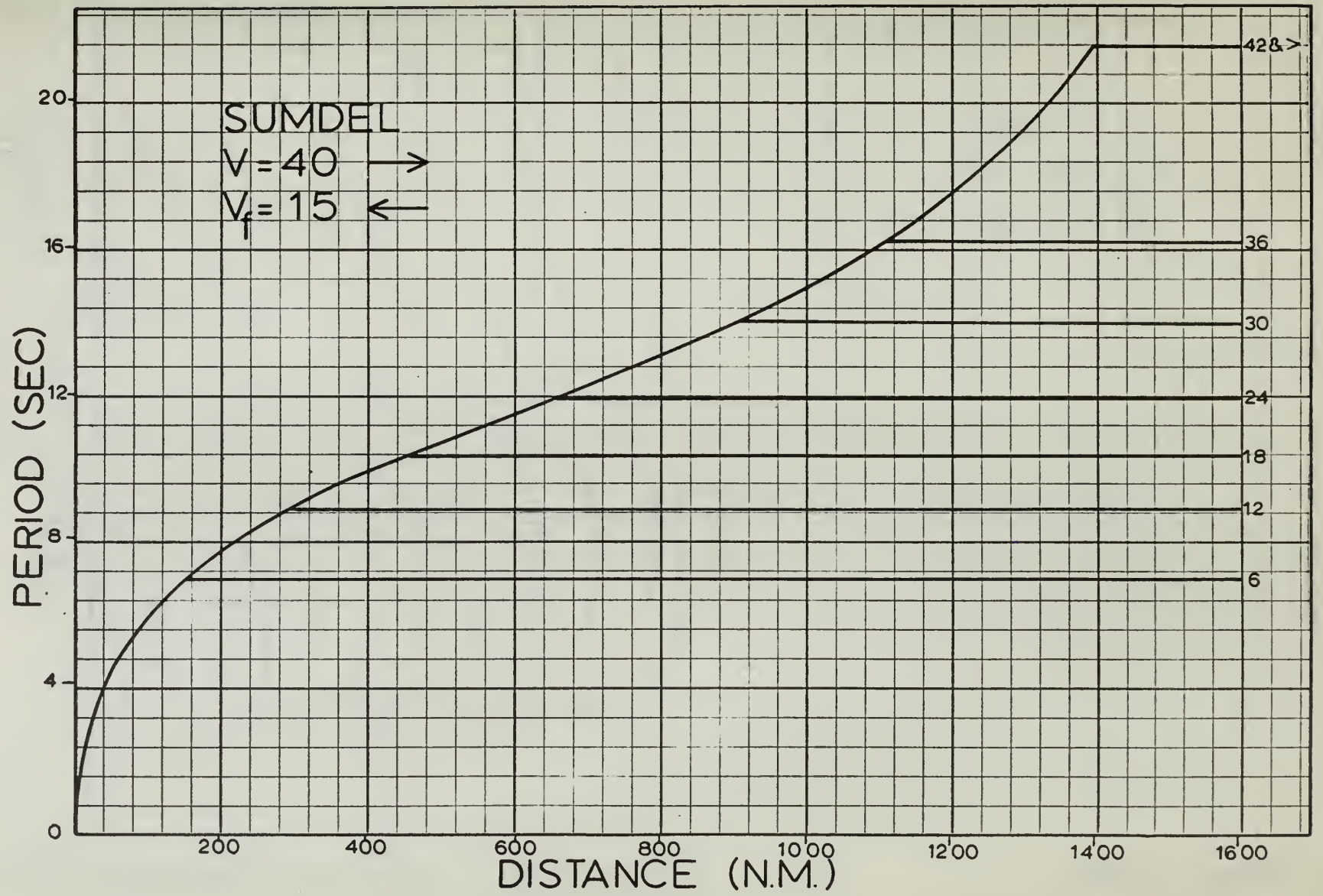



SUMDEL
V = 35 →
Vf = 35 ←
36 &>
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

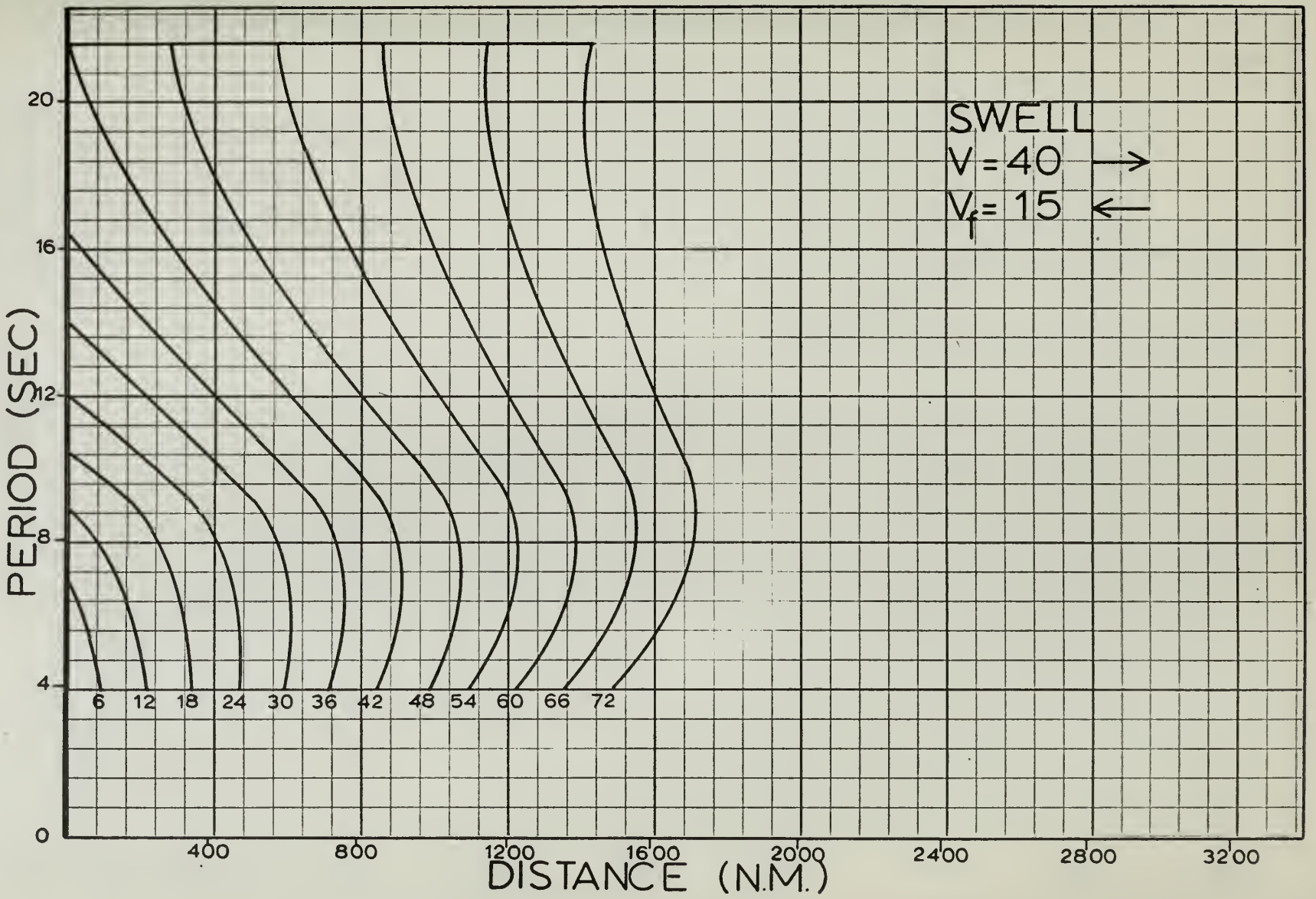



SWELL
V=35 →
V_f=35 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

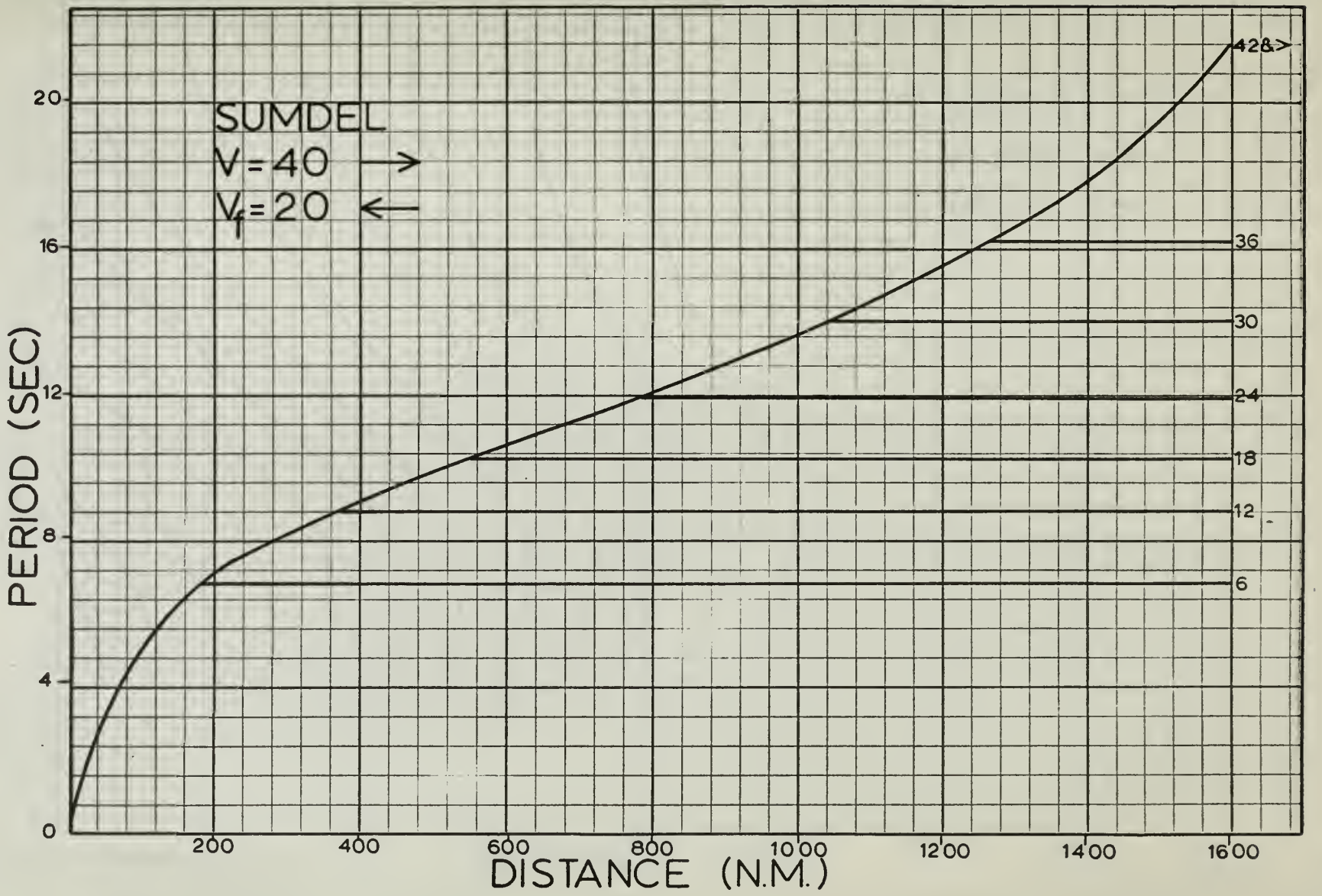



SUMDEL
V = 40 →
Vf = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
42&>
36
30
24
18
12
6

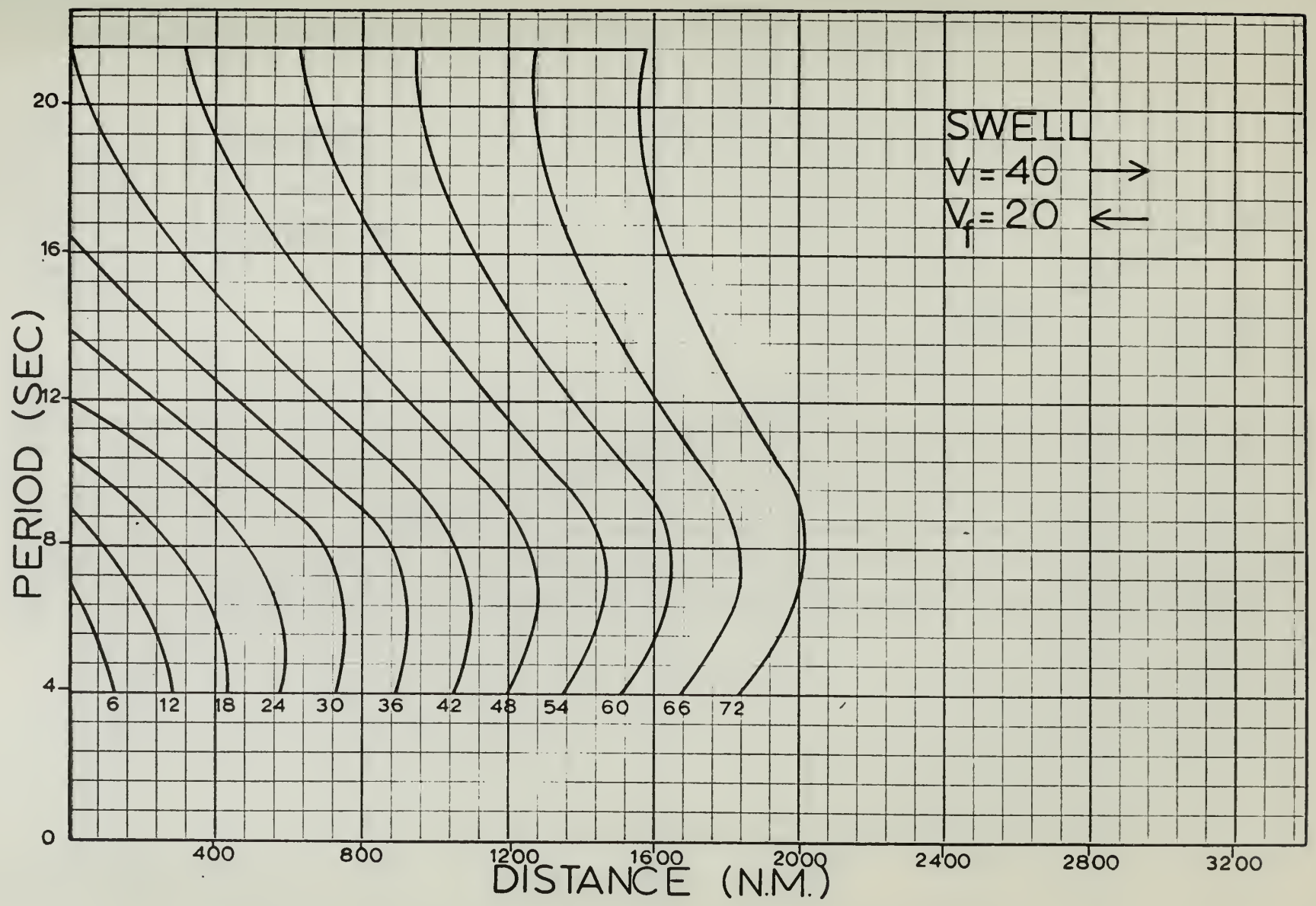



SWELL
V = 40
Vf = 15
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

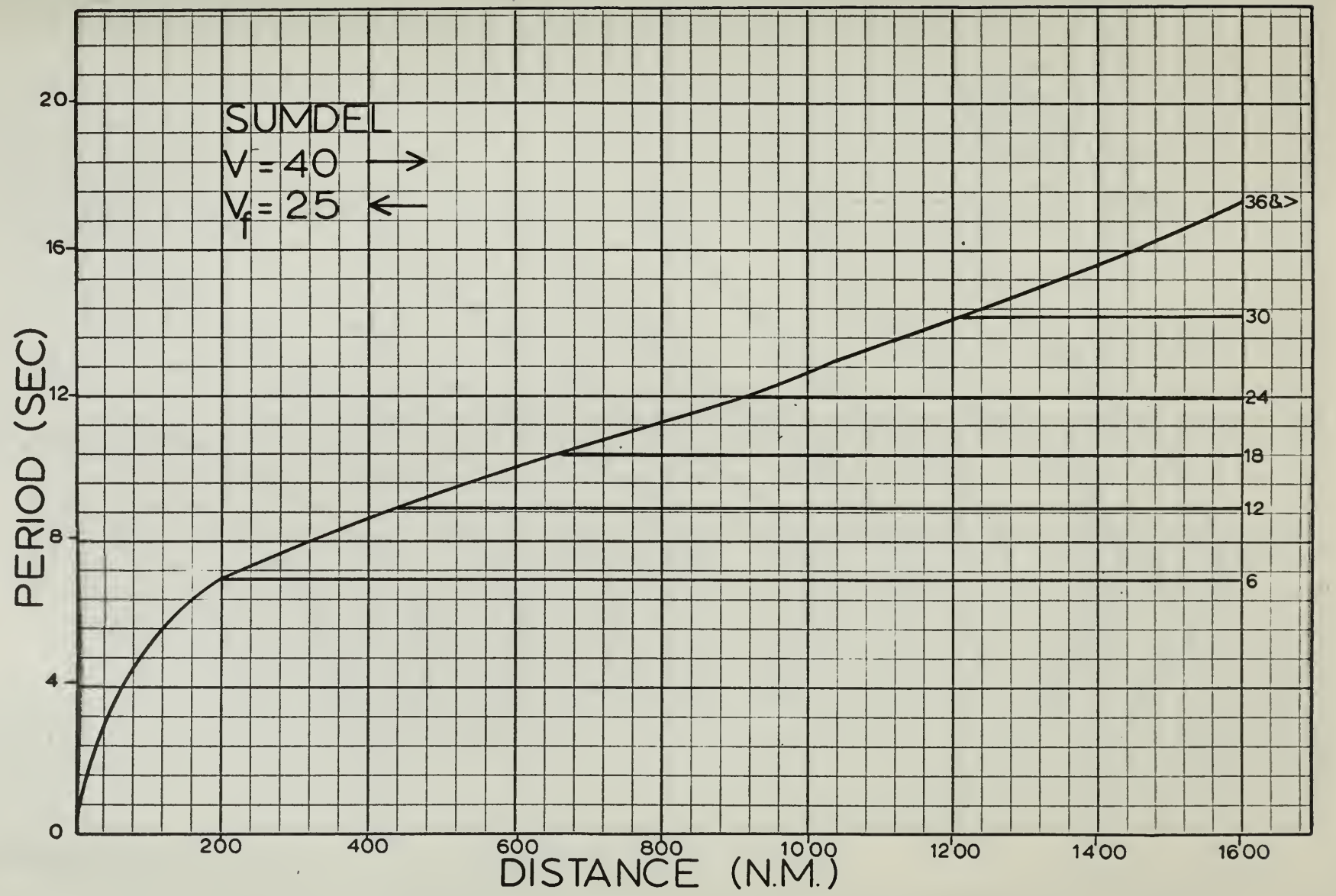



SUMDEL
V=40 →
Vf=20 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
42&>
36
30
24
18
12
6

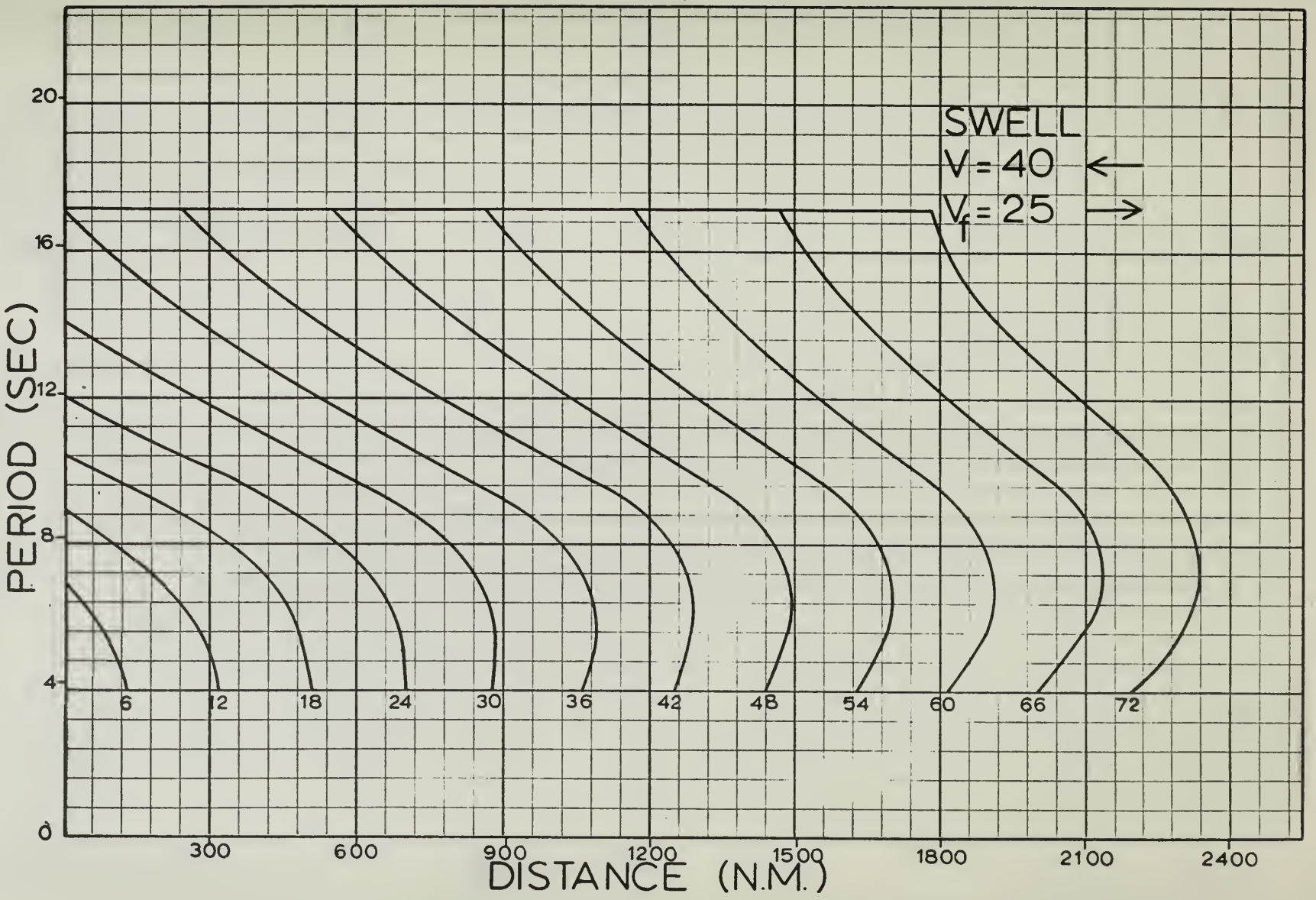



SWELL
V = 40 →
Vf = 20 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

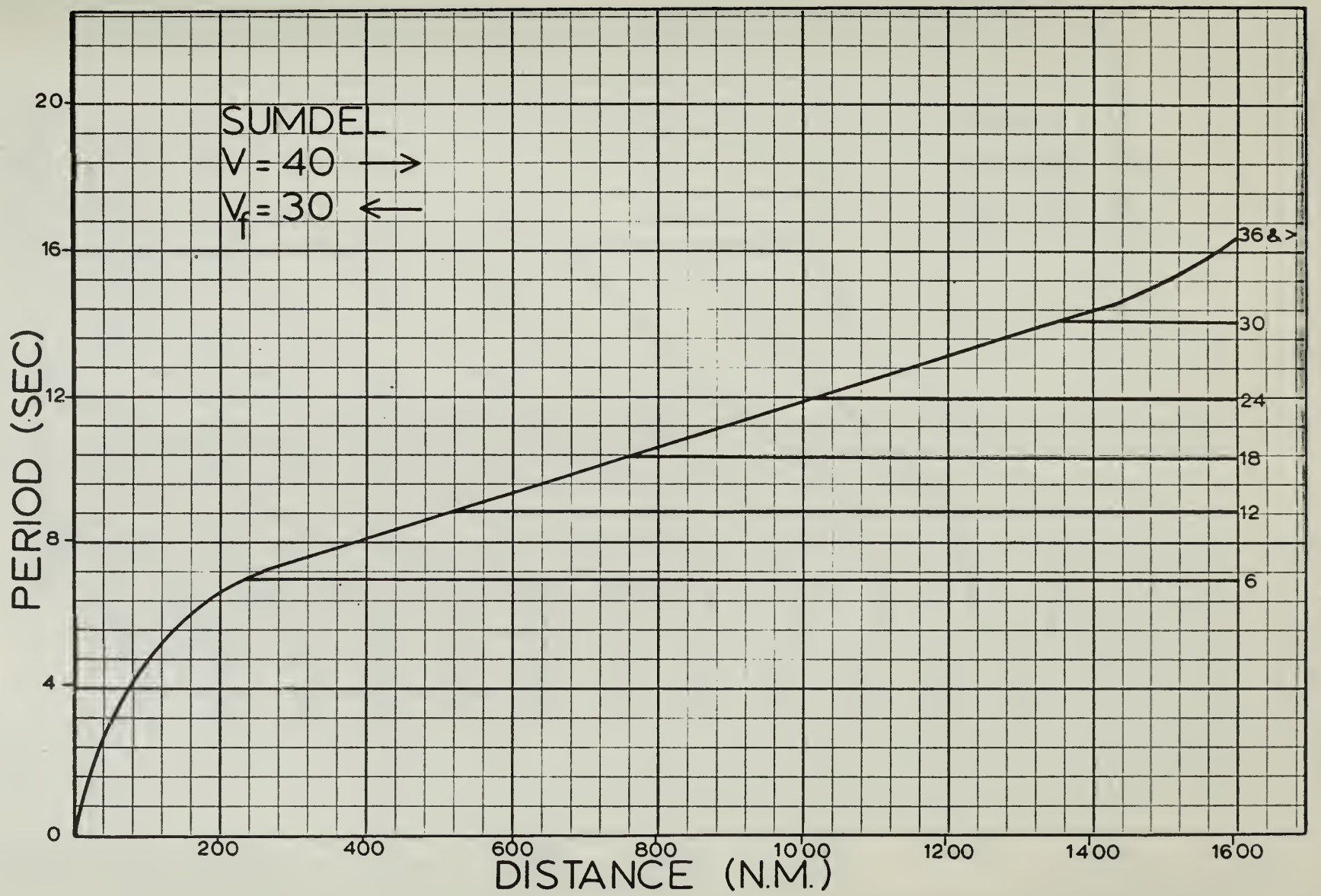



SUMDEL
V = 40 →
Vf = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36&>
30
24
18
12
6

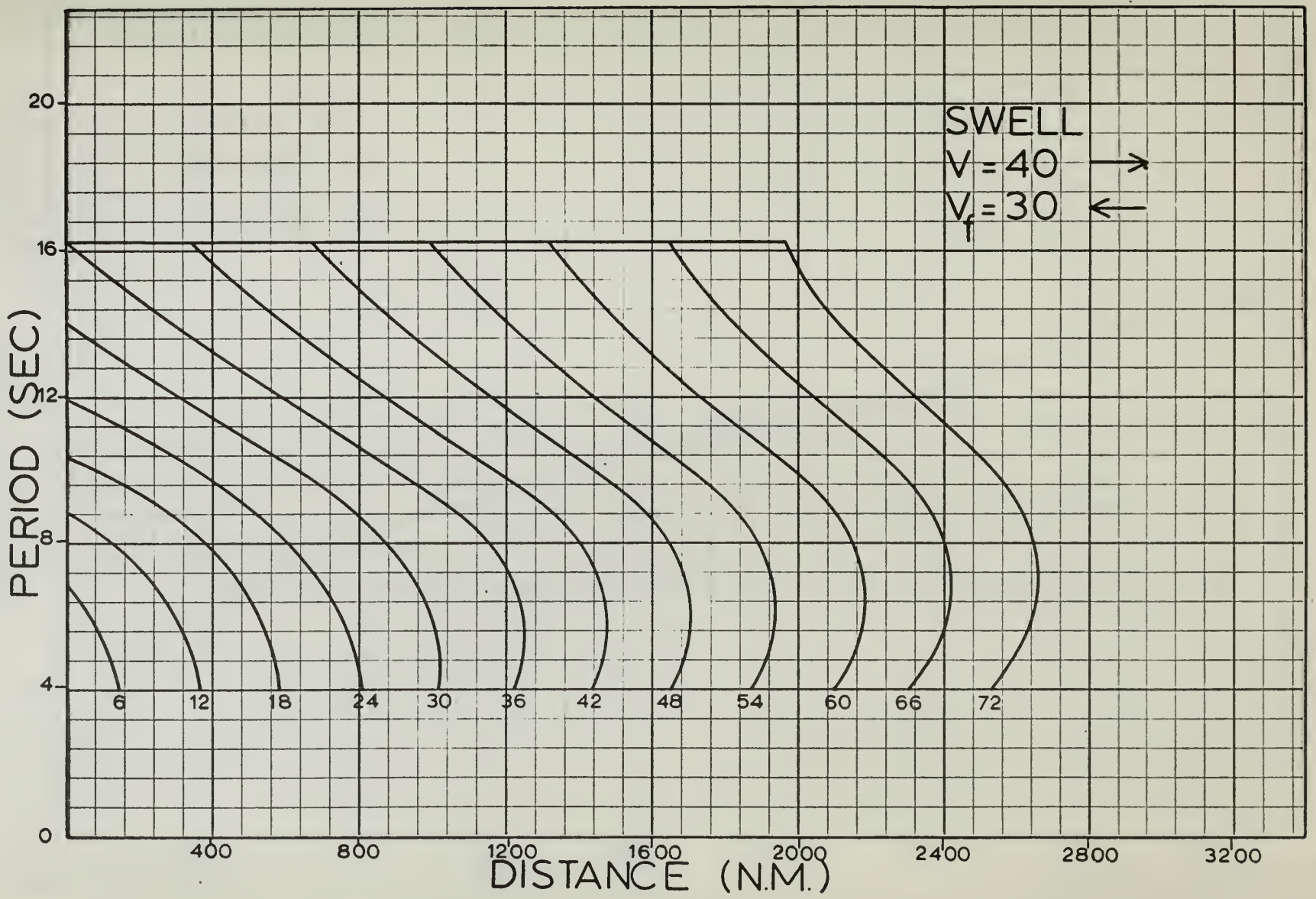



SWELL
V = 40
V_f = 25
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
300
600
900
1200
1500
1800
2100
2400
DISTANCE (N.M.)

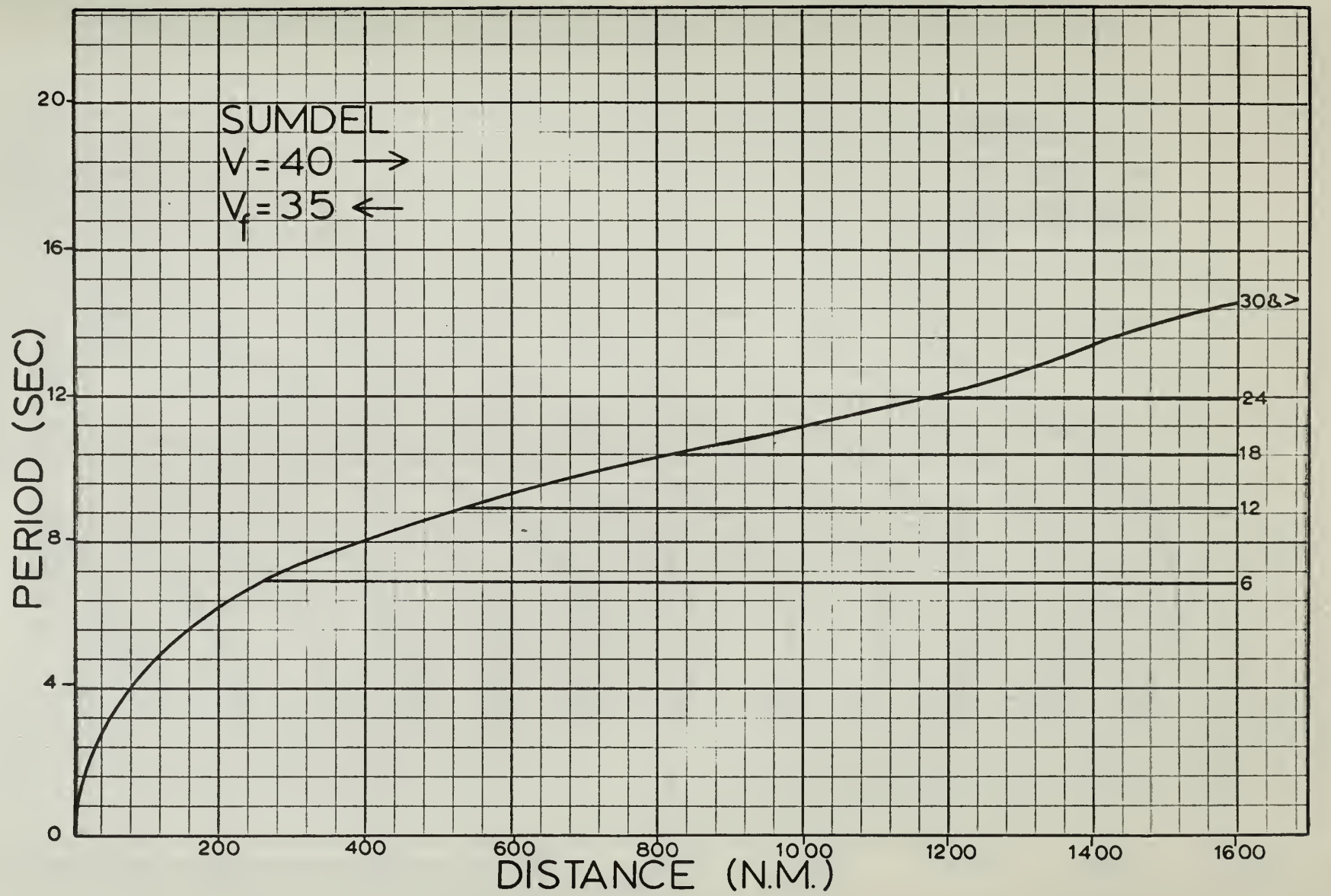



SUMDEL
V = 40 →
Vf = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36 &>
30
24
18
12
6

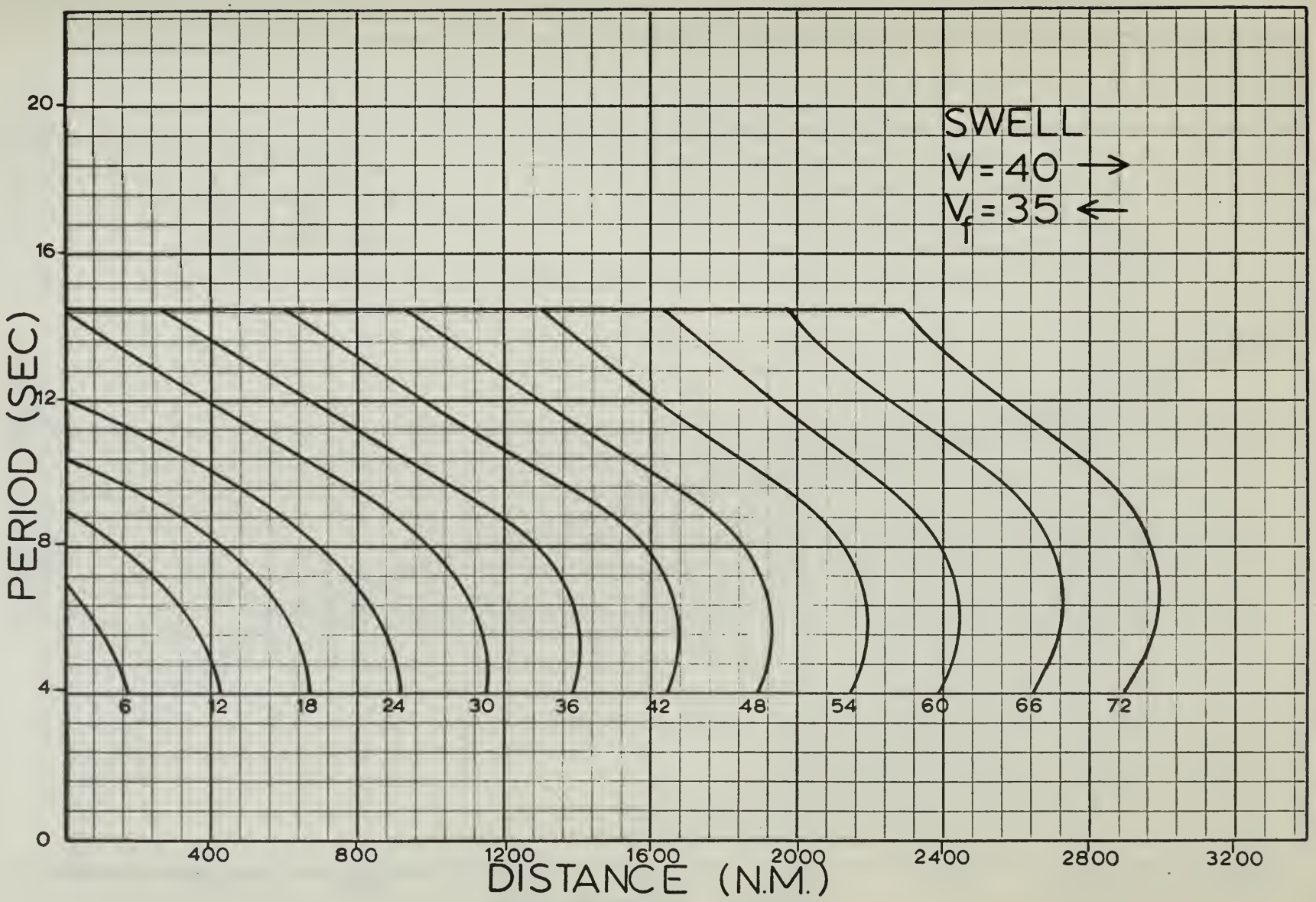



SWELL
V = 40
V_f = 30
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

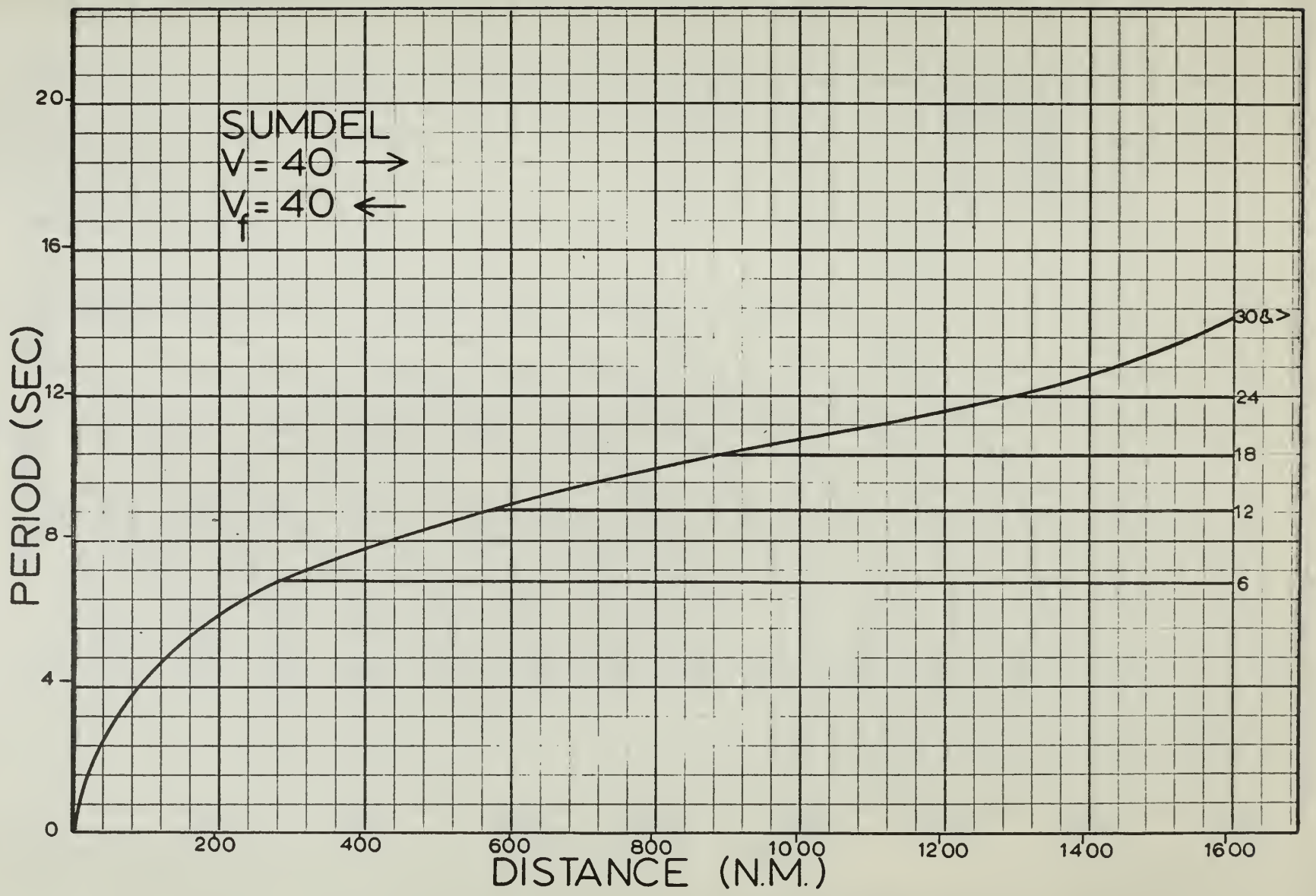



SUMDEL
V = 40 →
V_f = 35 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
30&>
24
18
12
6

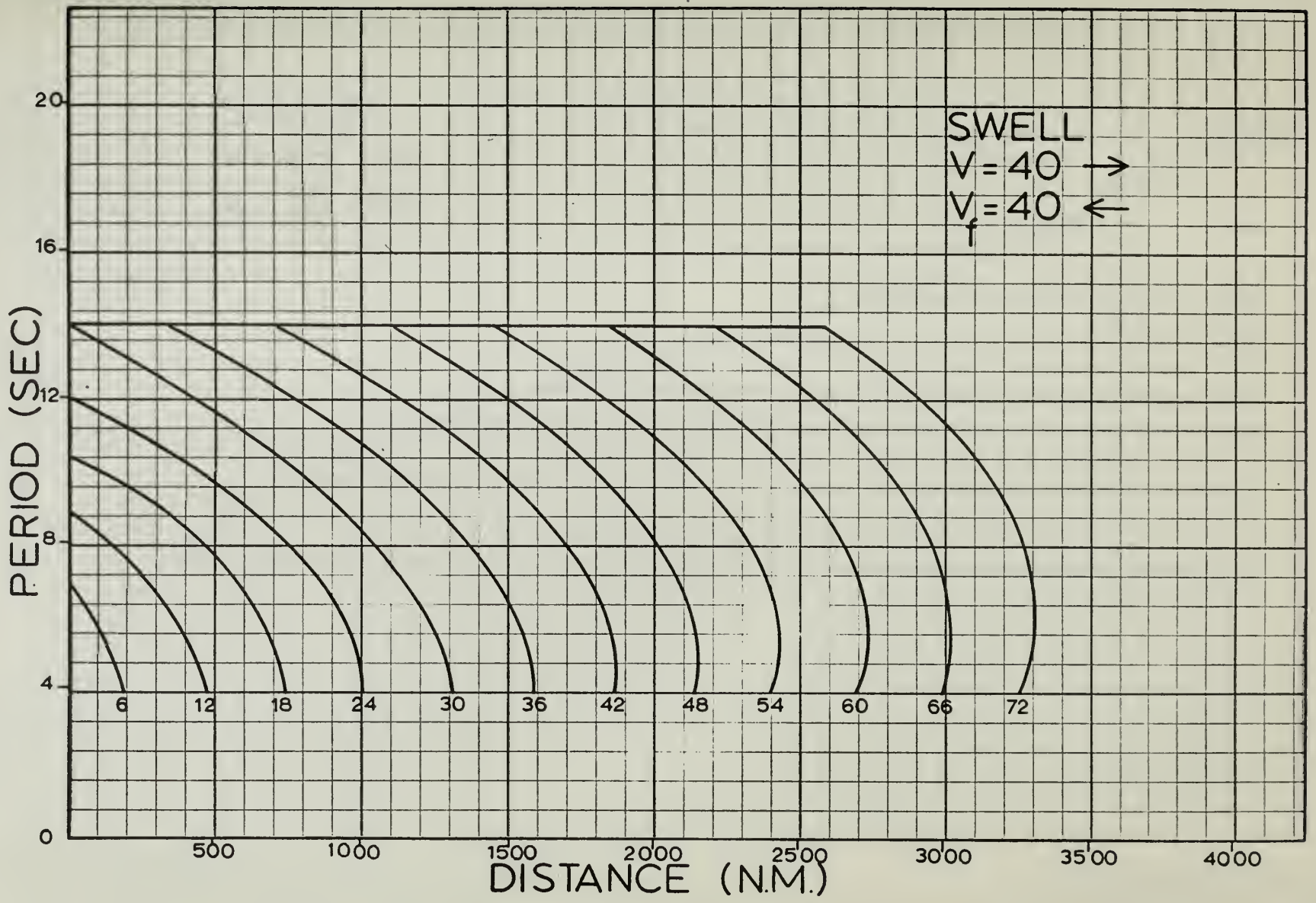



SWELL
V = 40 →
V_f = 35 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

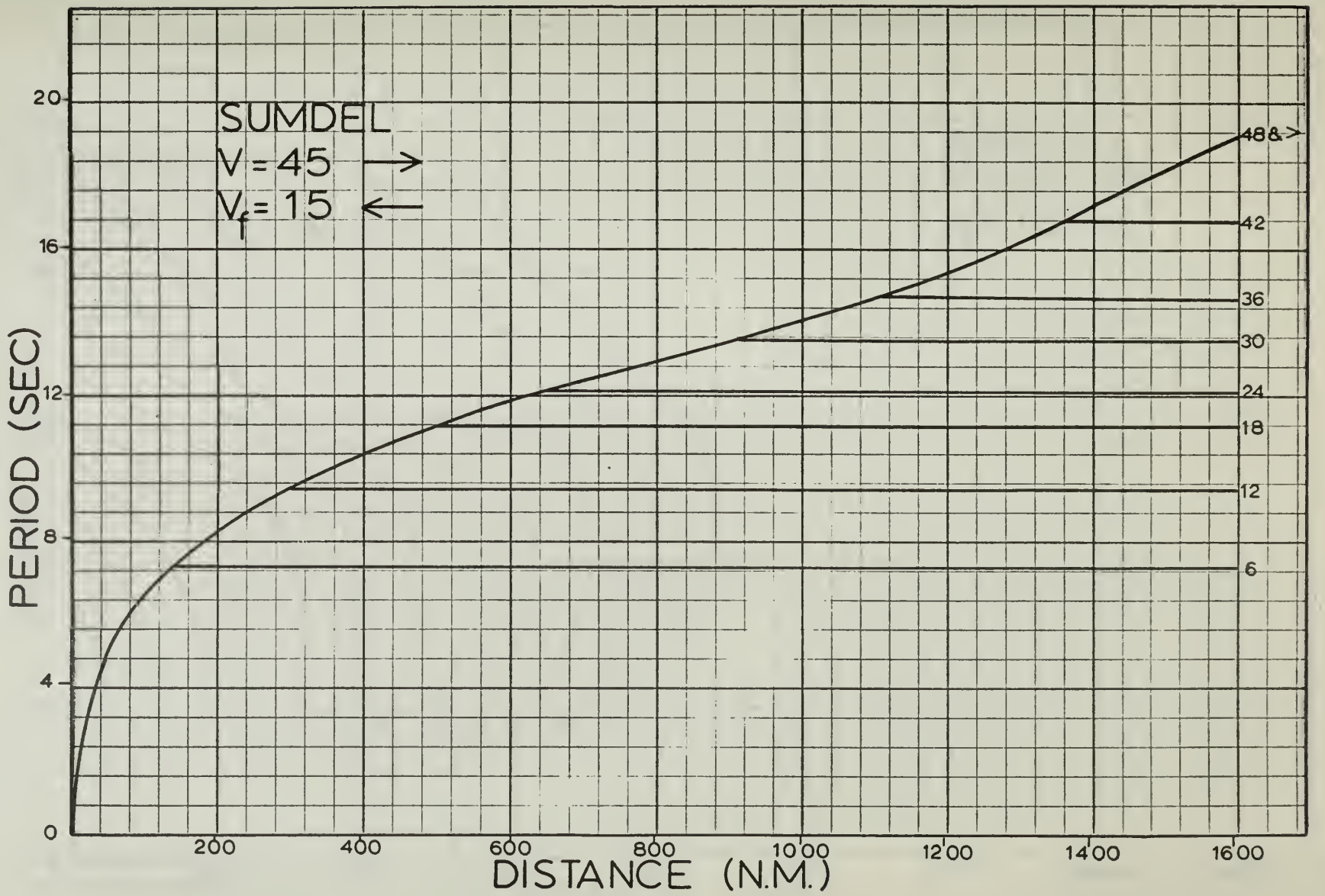



SUMDEL
V = 40 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
30&>
24
18
12
6

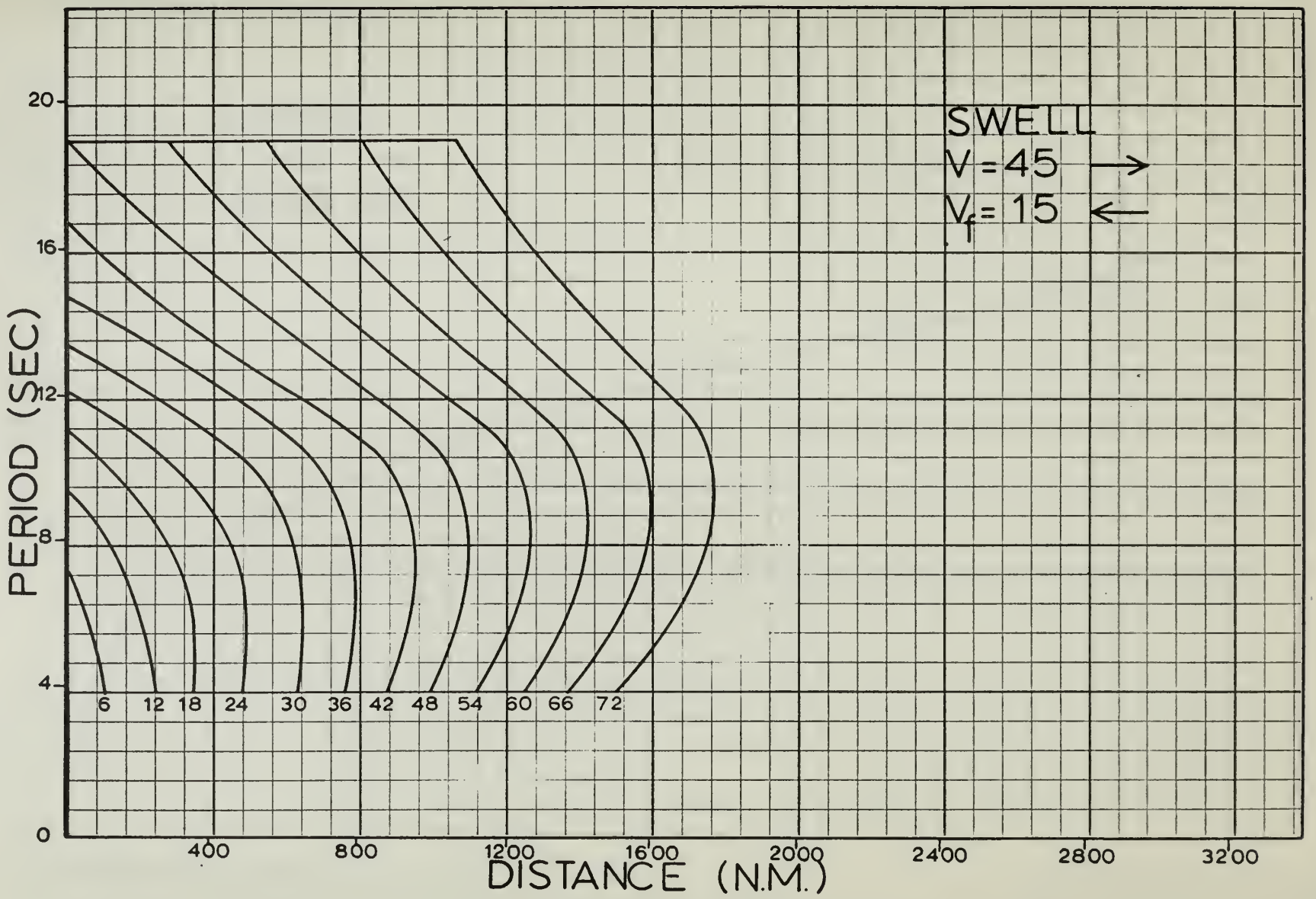



SWELL
V = 40 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE (N.M.)

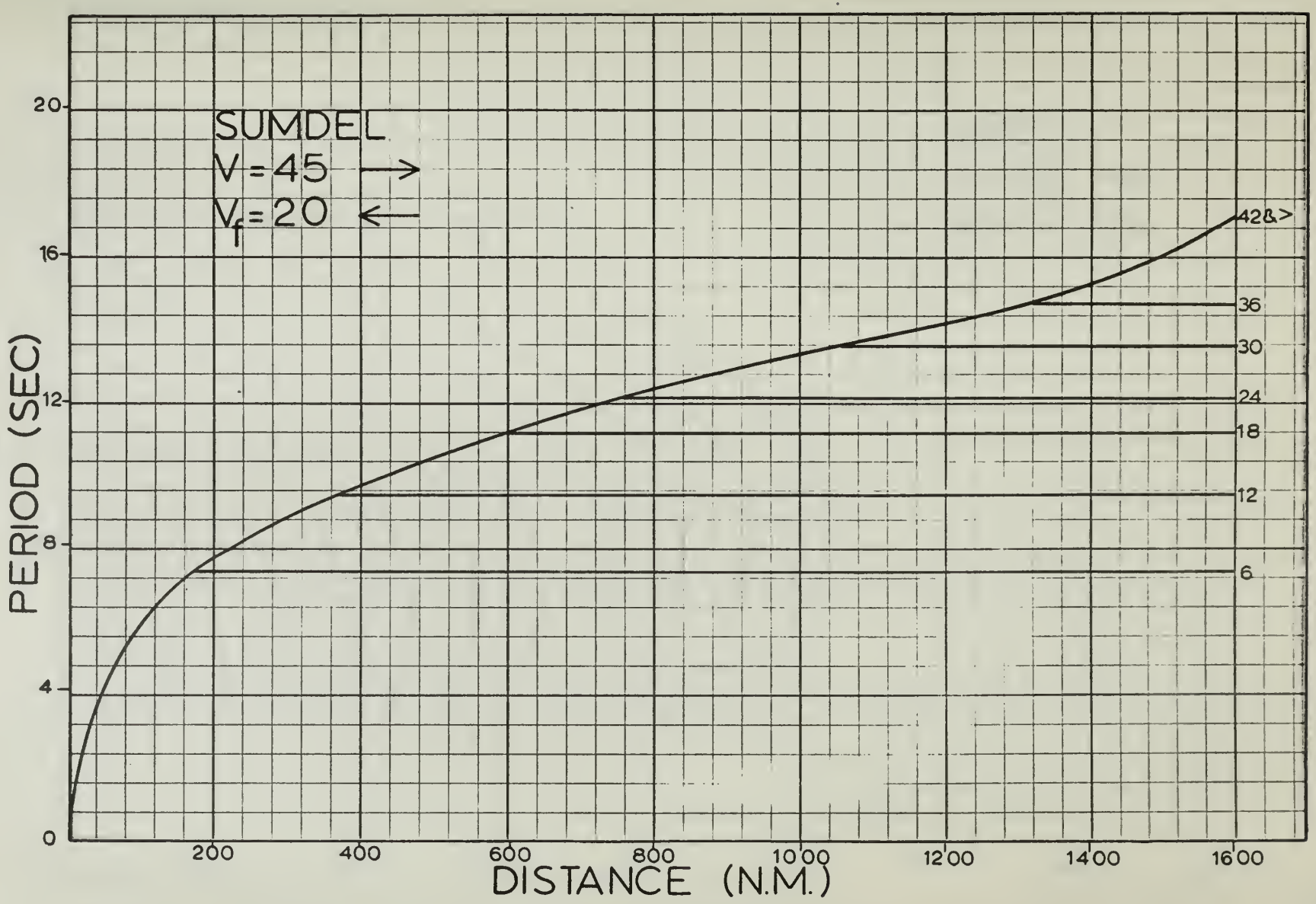



SUMDEL
V = 45 →
V_f = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
48 &
42
36
30
24
18
12
6

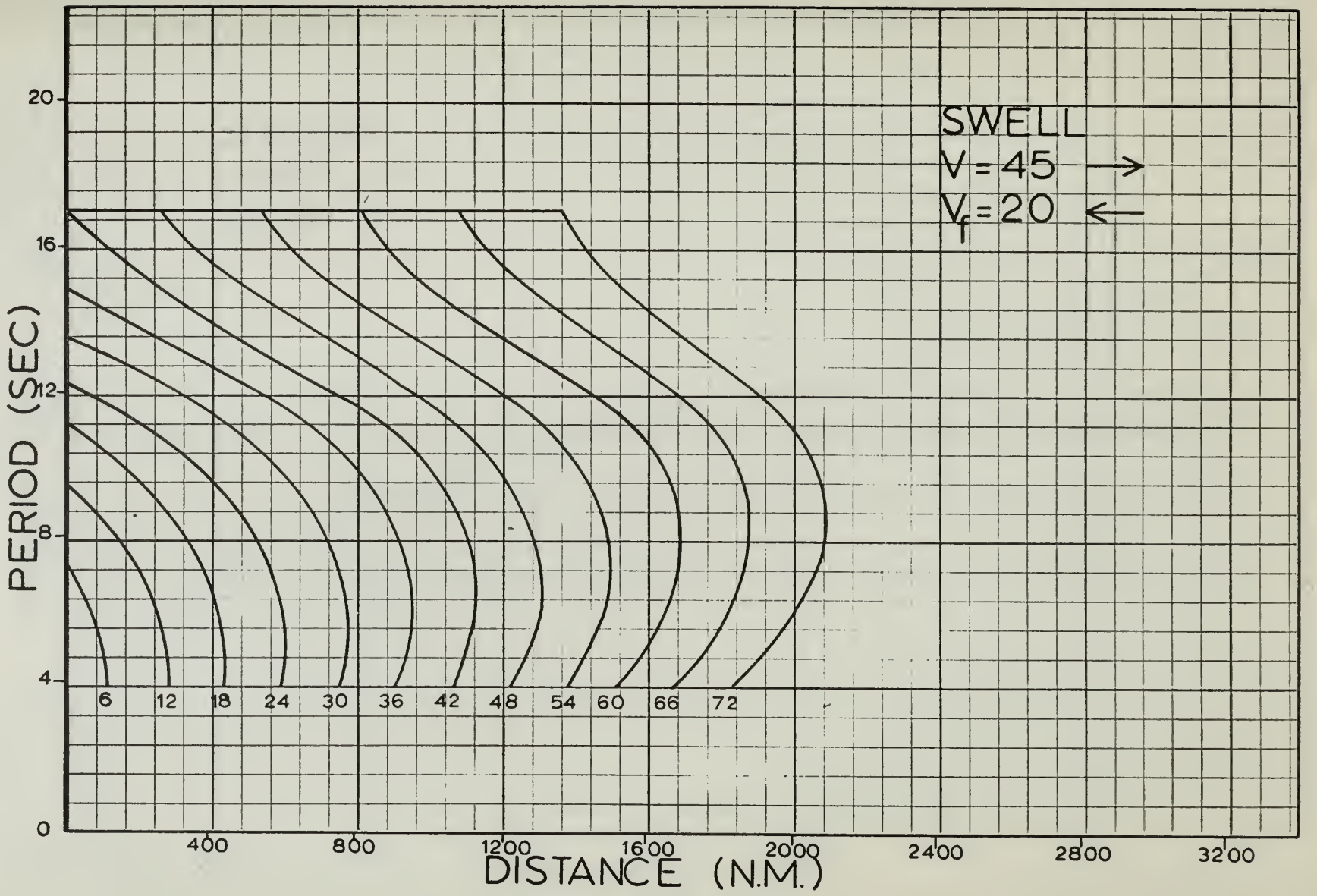



SWELL
V = 45 →
V_f = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

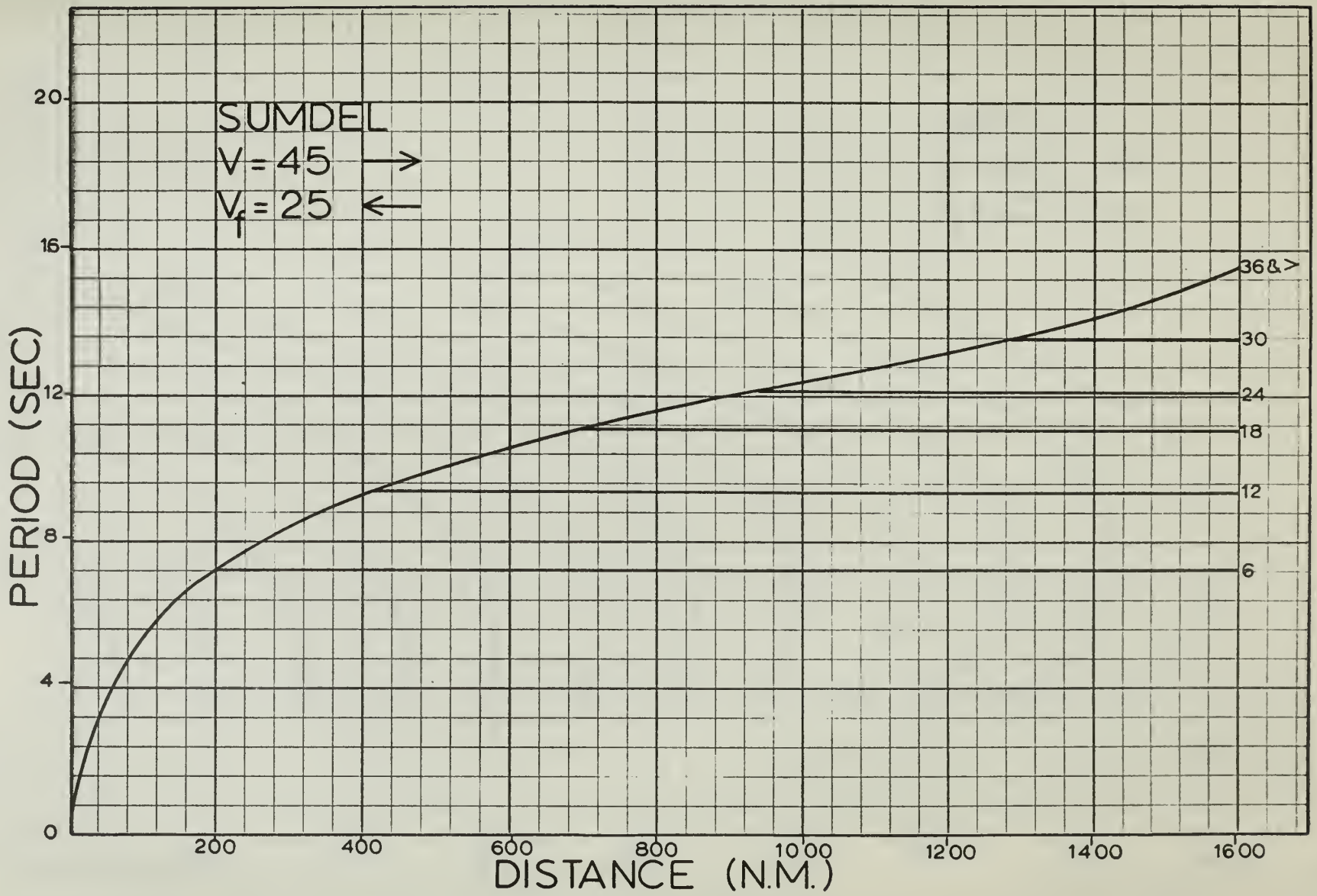



SUMDEL
V=45 →
V_f=20 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
42&>
36
30
24
18
12
6

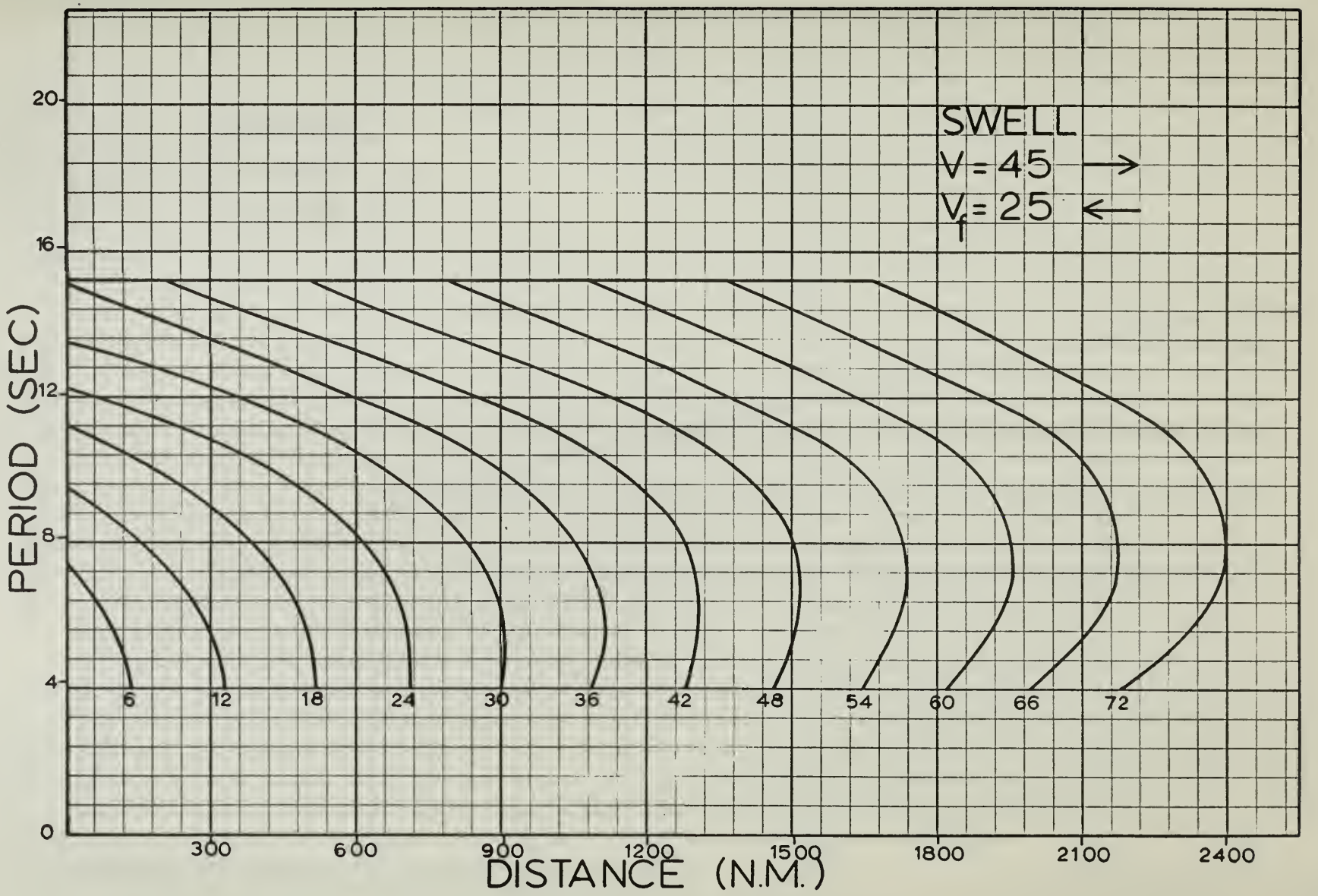



SWELL
V = 45 →
V_f = 20 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

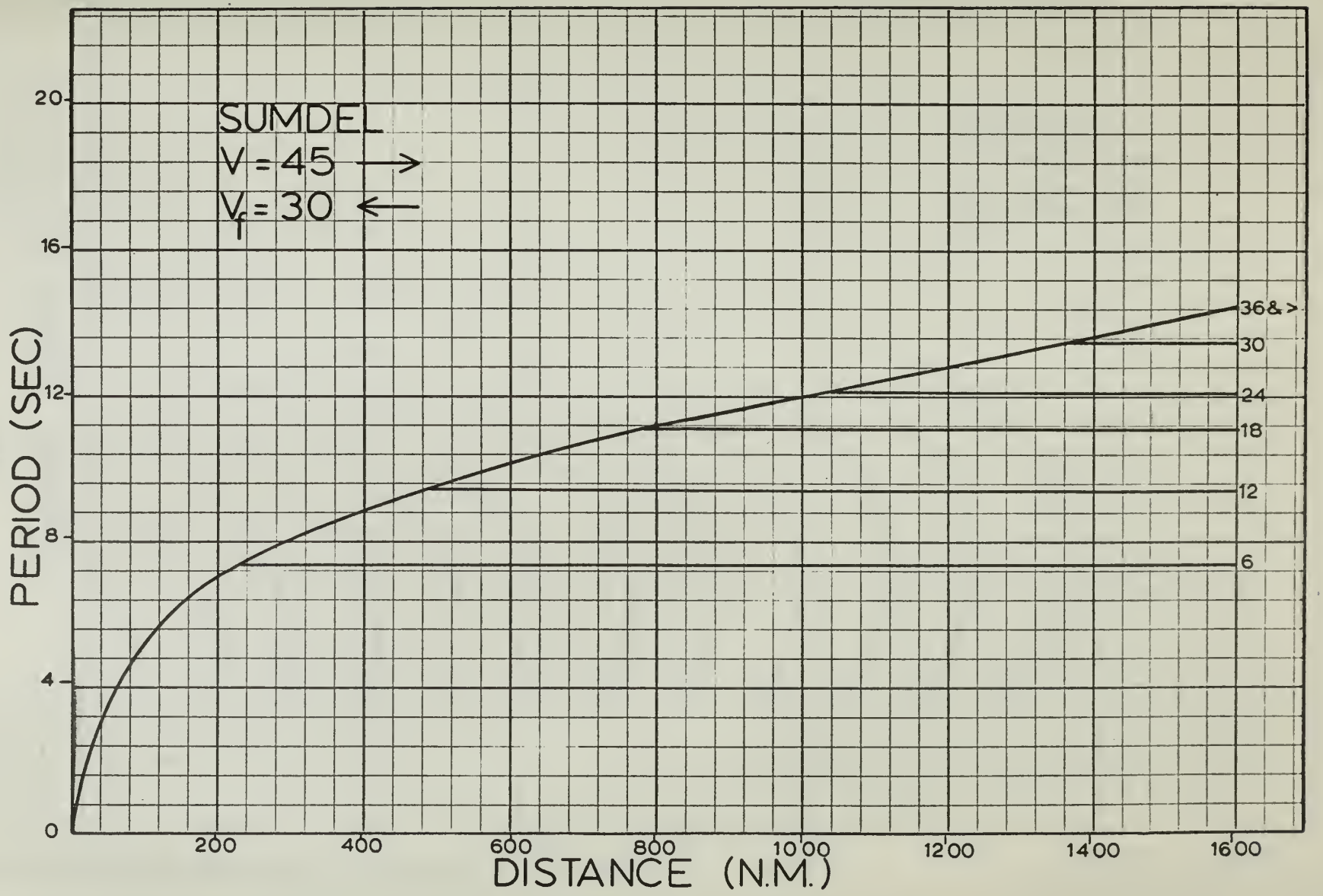



SUMDEL
V = 45 →
V_f = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36 &>
30
24
18
12
6

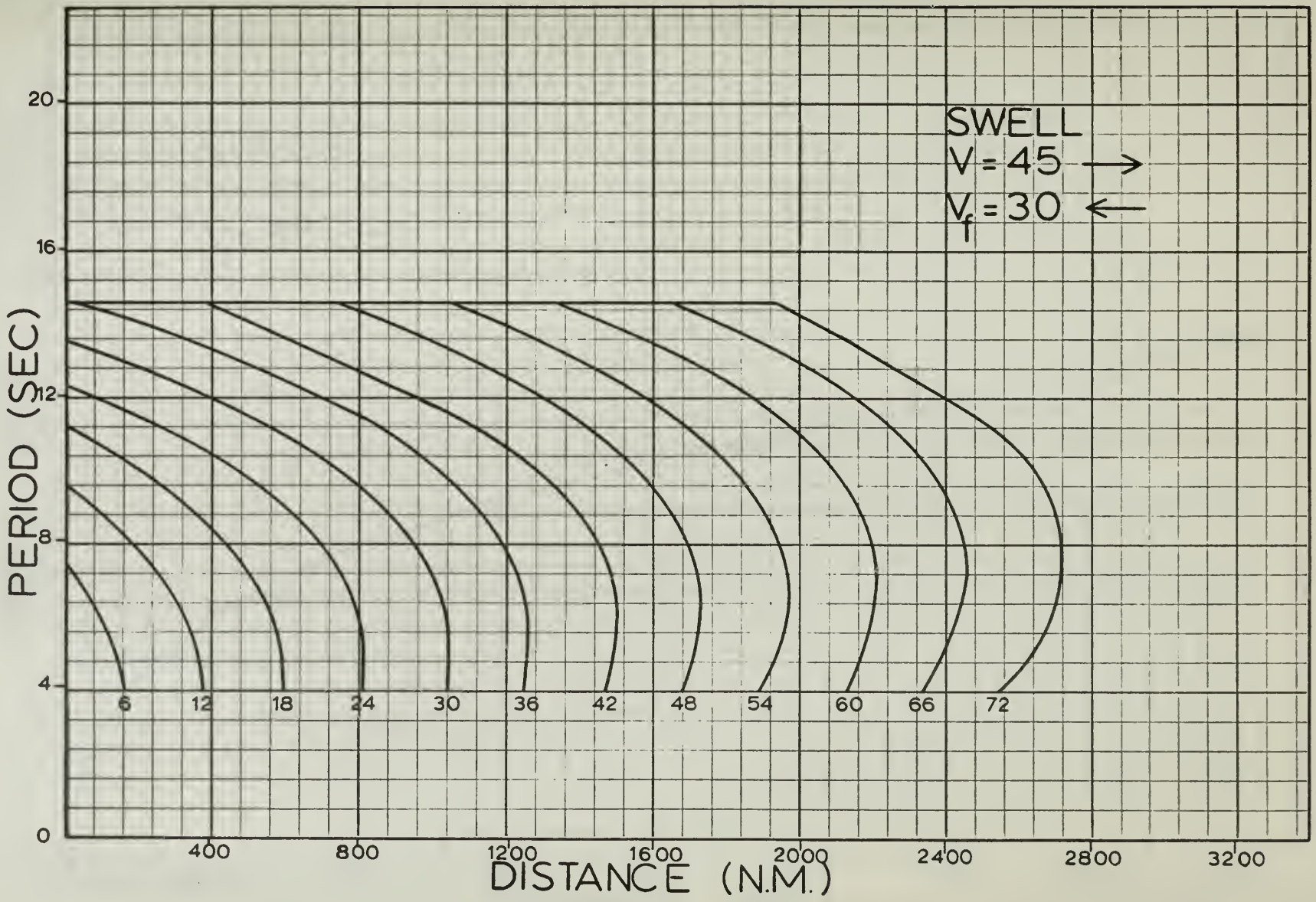



SWELL
V = 45
V_f = 25
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
300
600
900
1200
1500
1800
2100
2400
DISTANCE (N.M.)

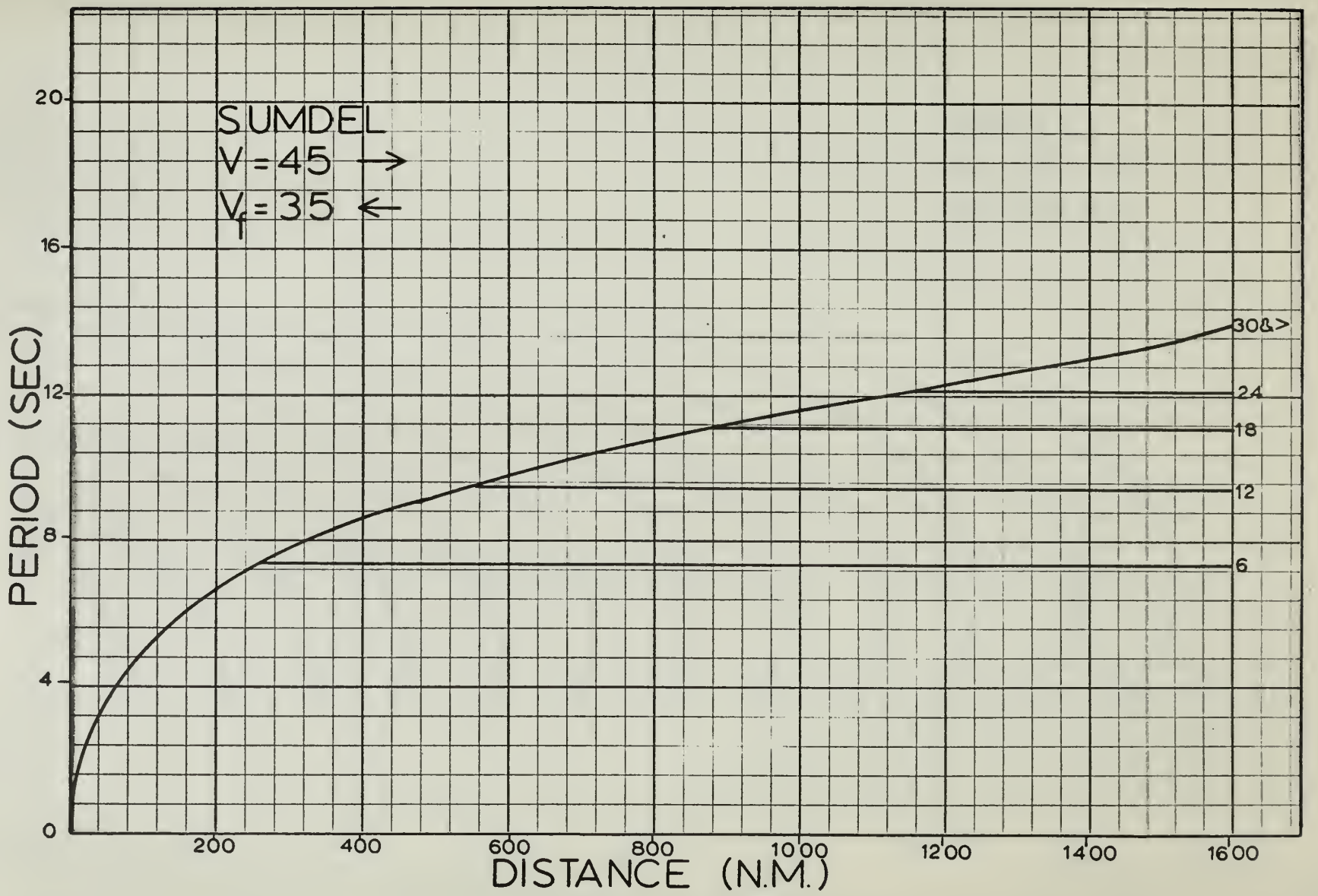



SUMDEL
V = 45 →
Vf = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36 & >
30
24
18
12
6

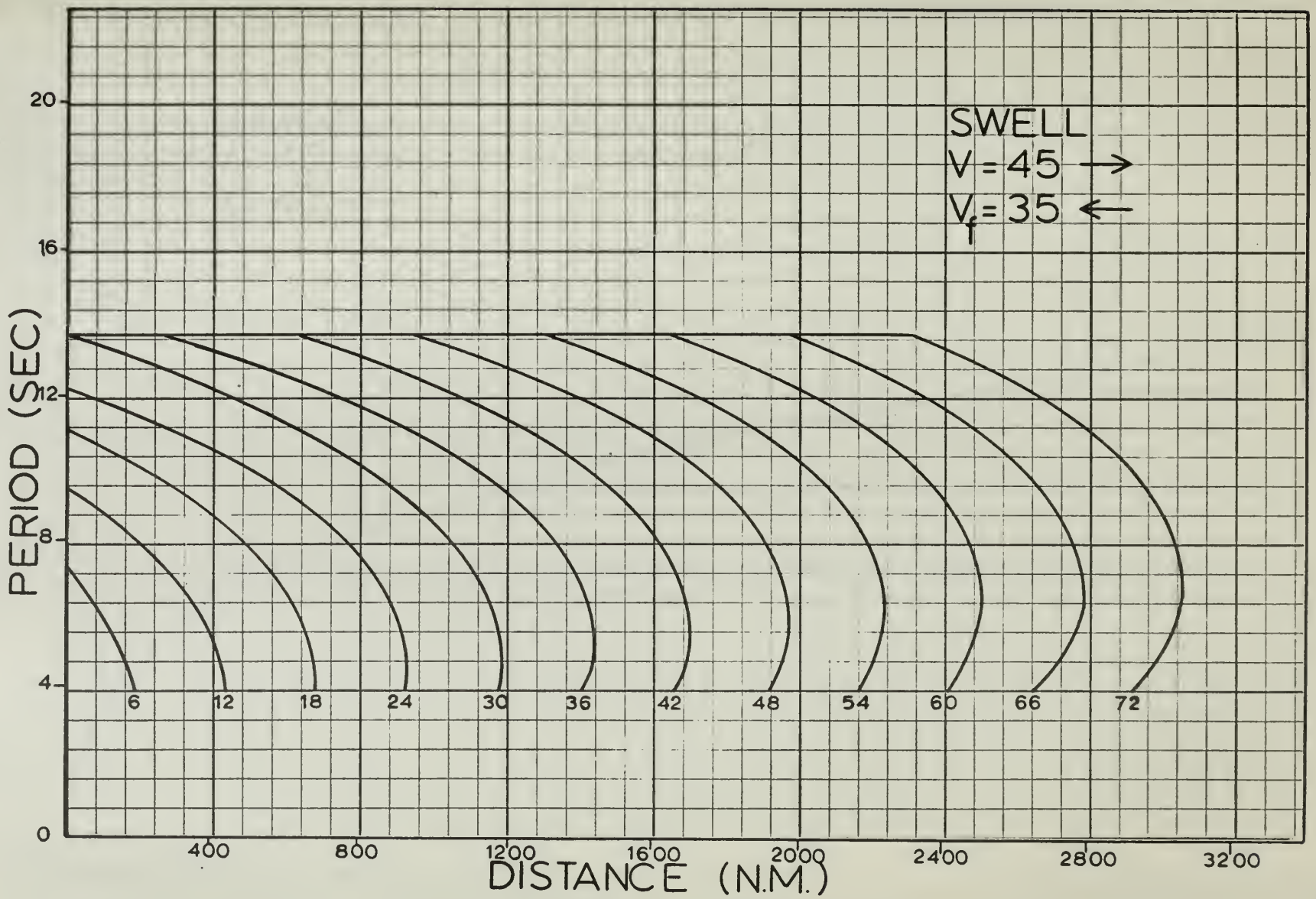



SWELL
V = 45 →
V_f = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

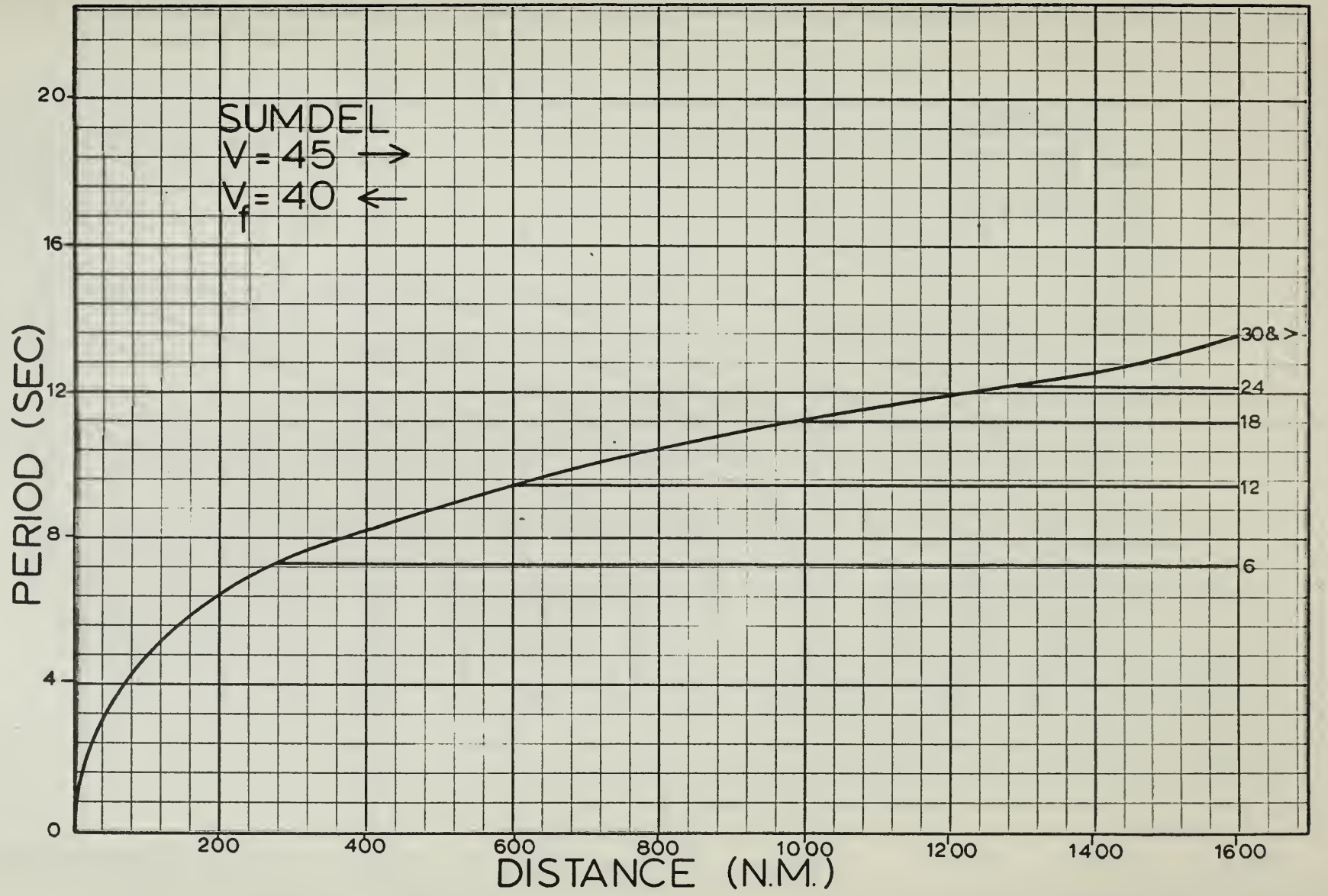



SUMDEL
V = 45 →
V_T = 35 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
30&>
24
18
12
6

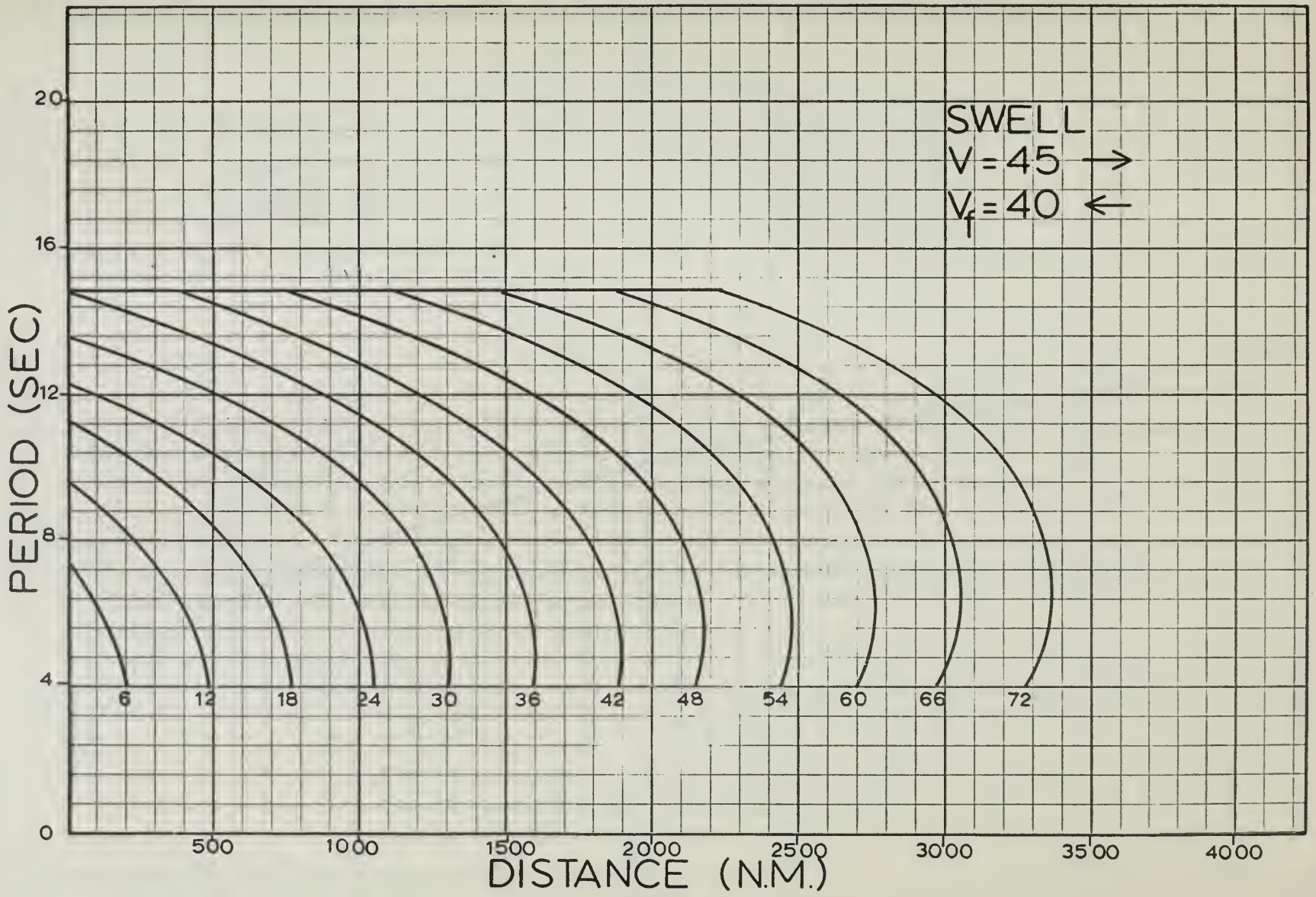


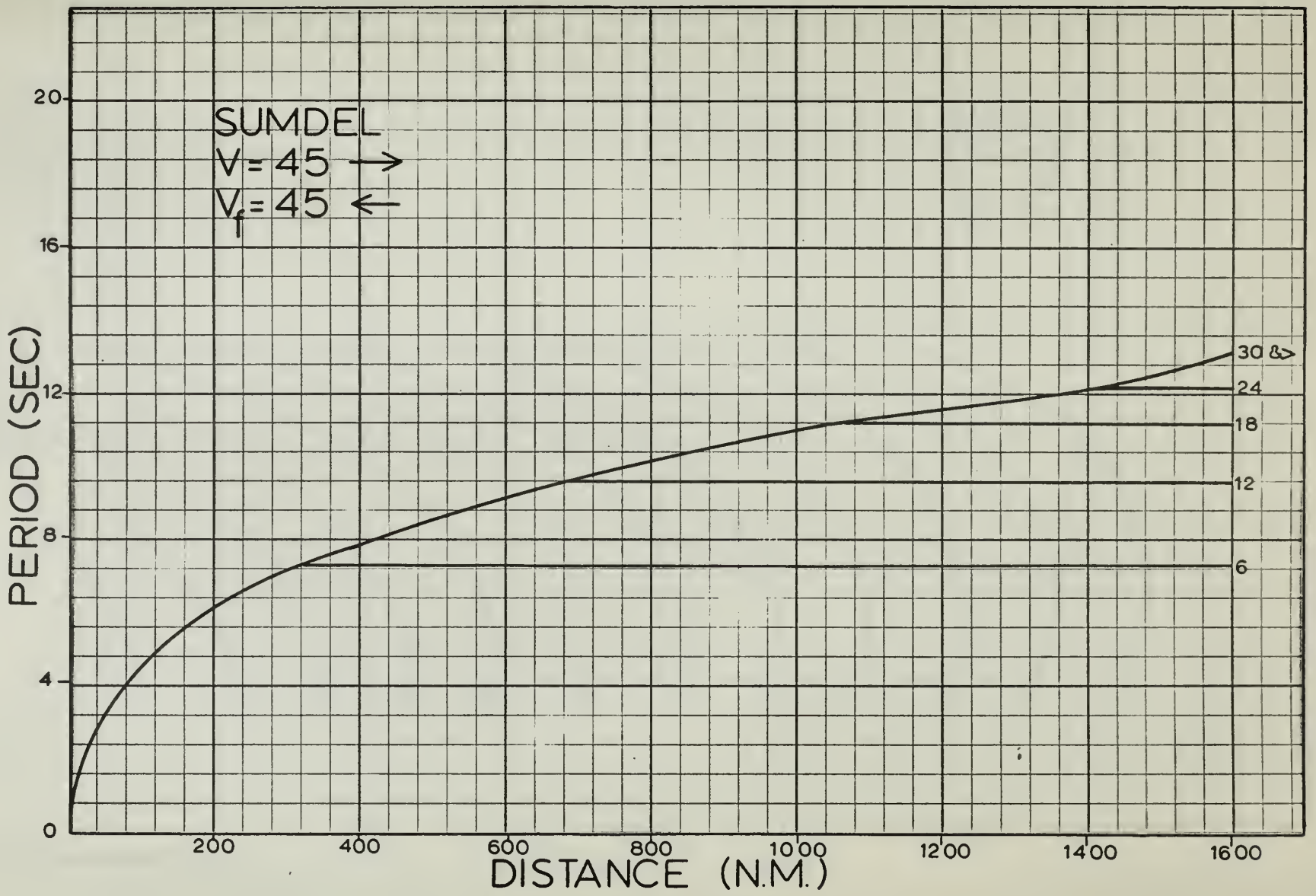

SWELL
V = 45 →
Vf = 35 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)




SUMDEL
V = 45 →
Vf = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
30&>
24
18
12
6

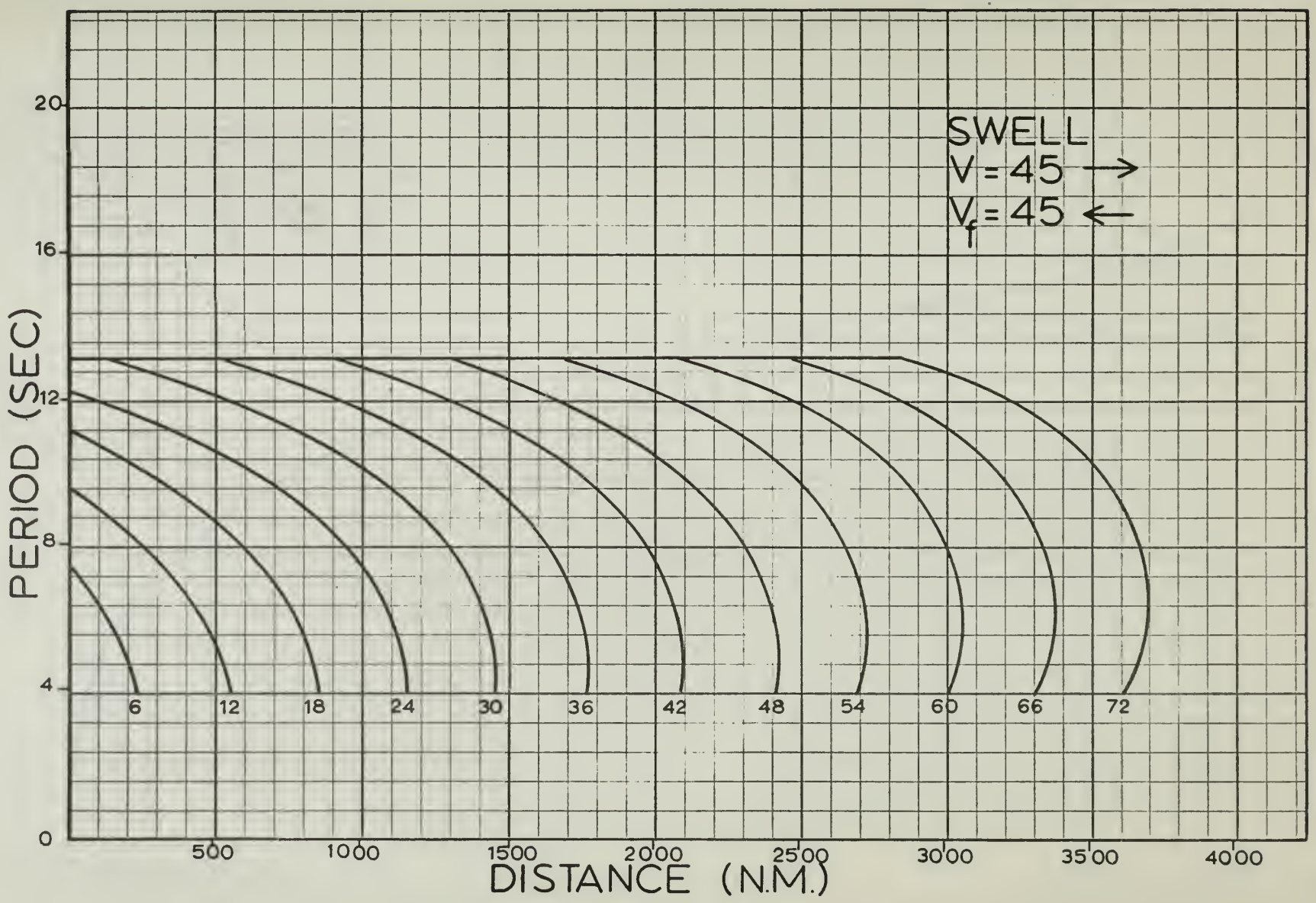



SWELL
V = 45 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE (N.M.)

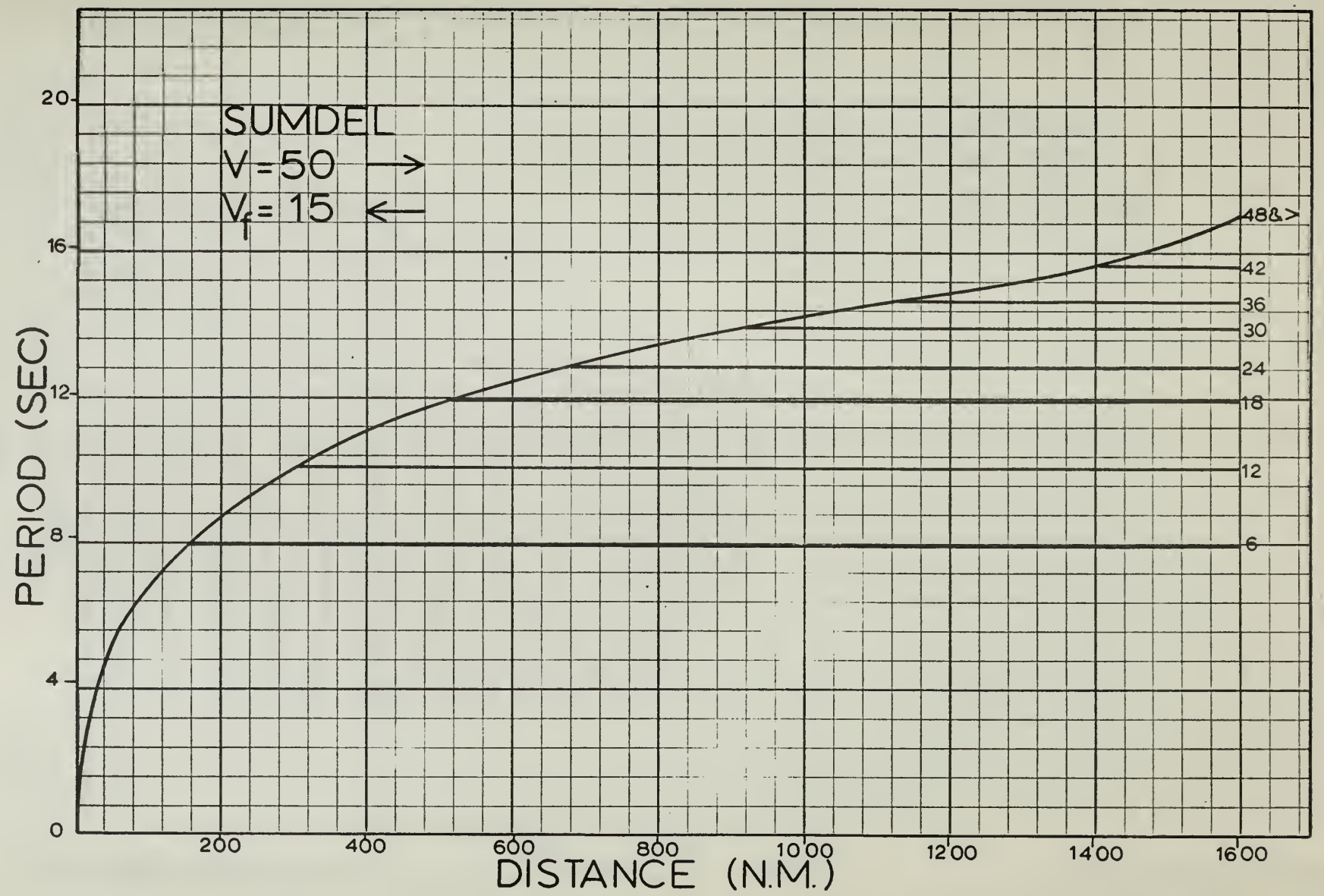

SUMDEL
V = 45 →
Vf = 45 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
30 &>
24
18
12
6

268

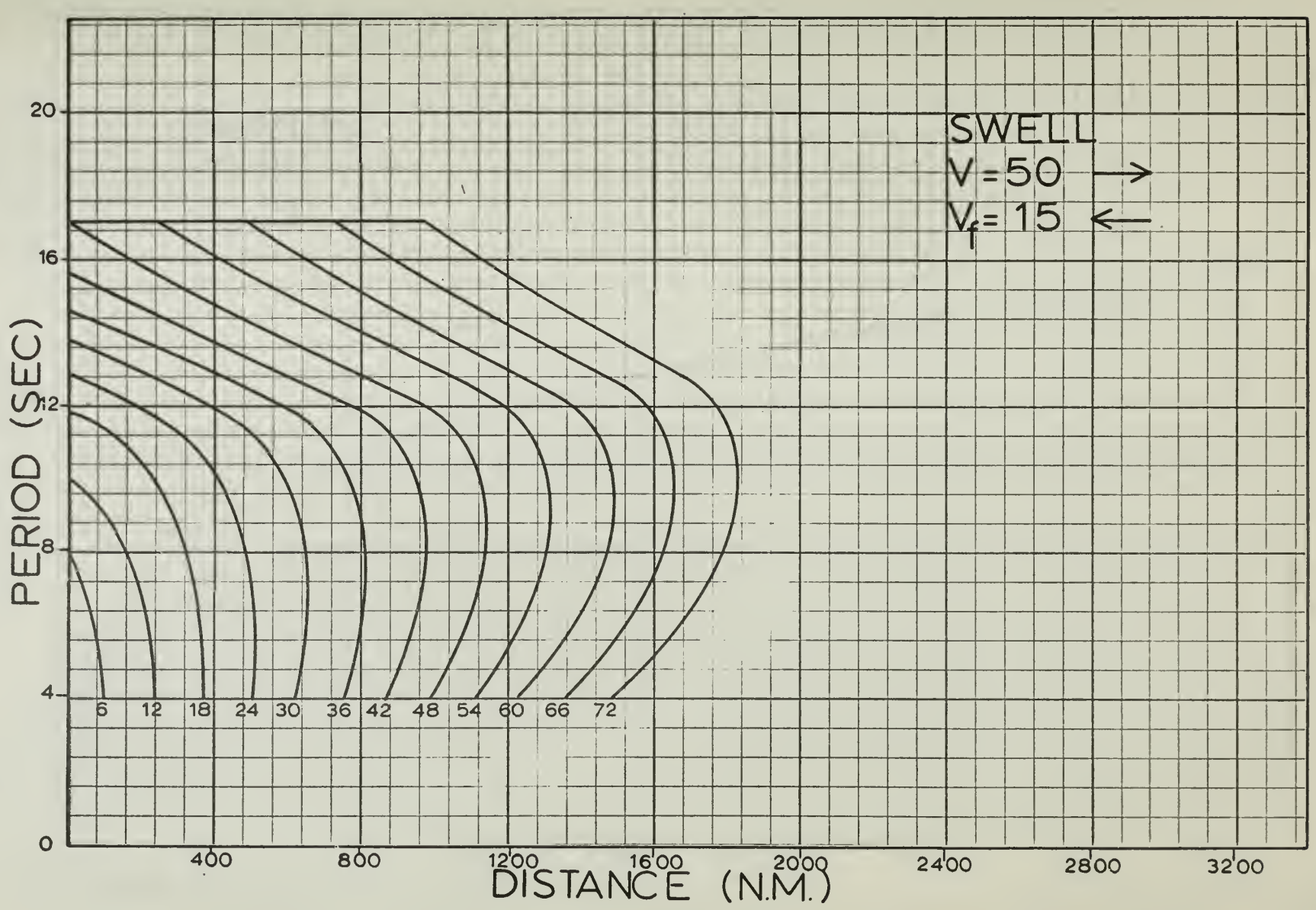



SWELL
V = 45 →
V_f = 45 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE (N.M.)

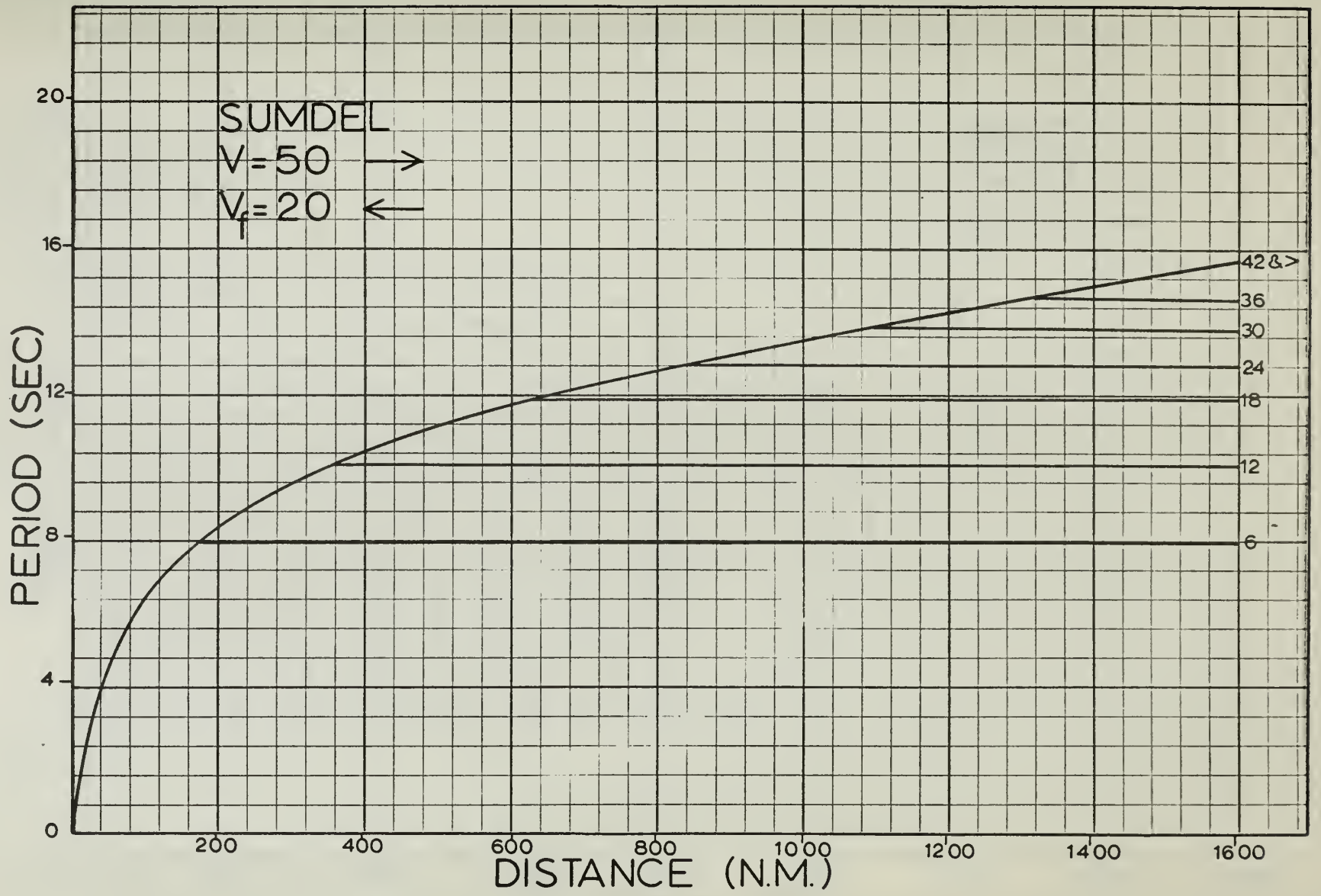


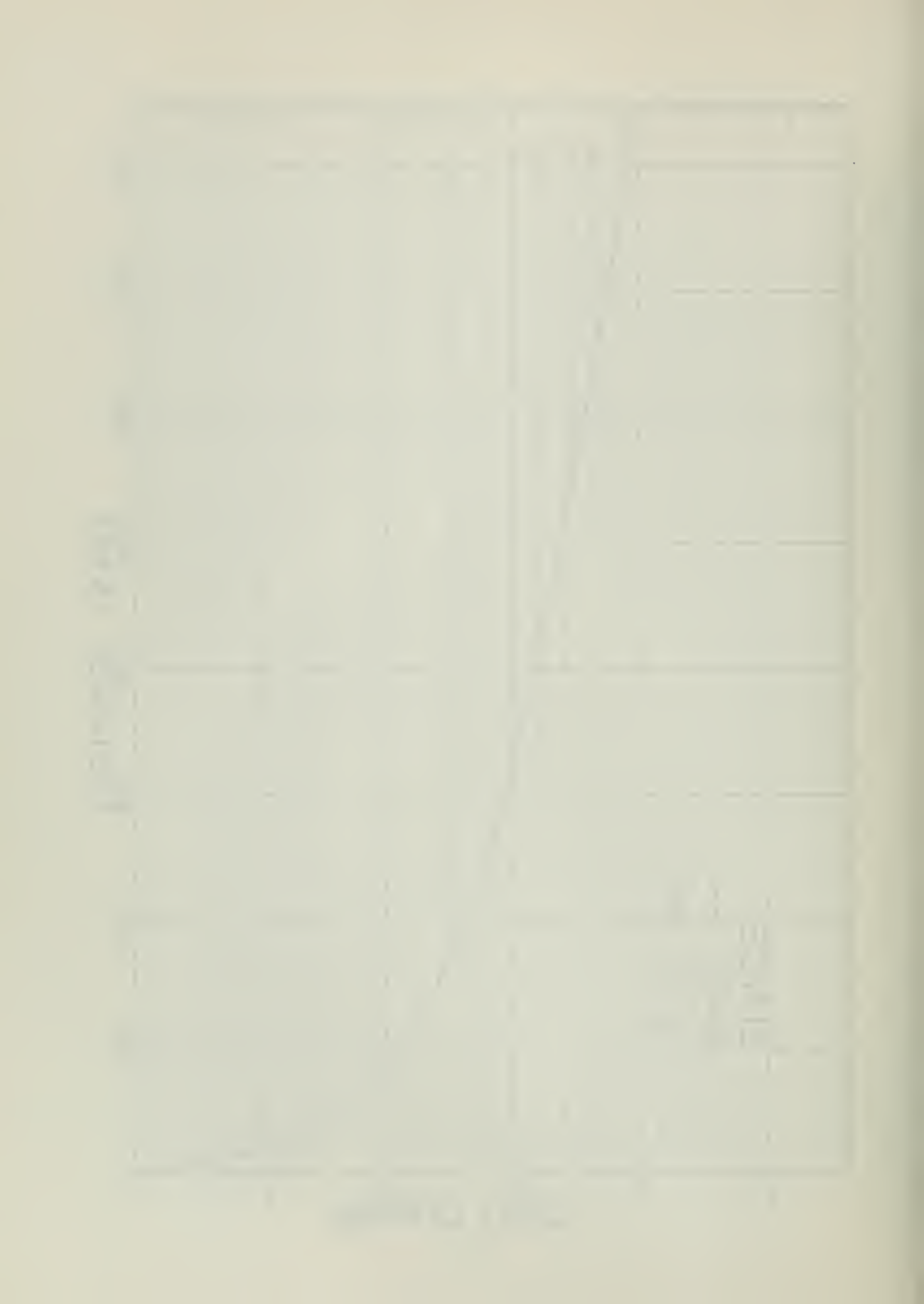

SUMDEL
V=50 →
V_f=15 ←
48&>
42
36
30
24
18
12
6
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)

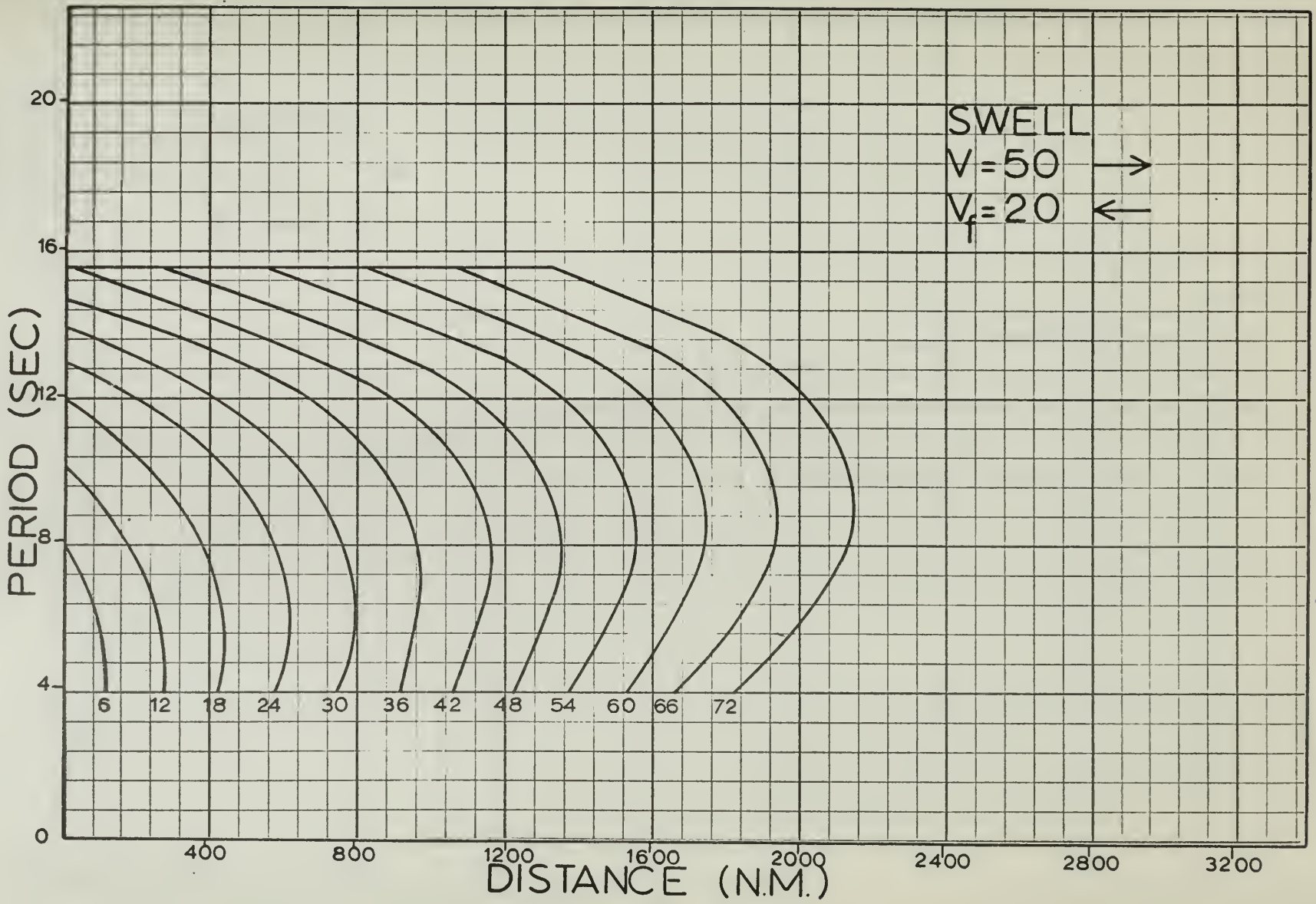



SWELL
V = 50 →
V_f = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

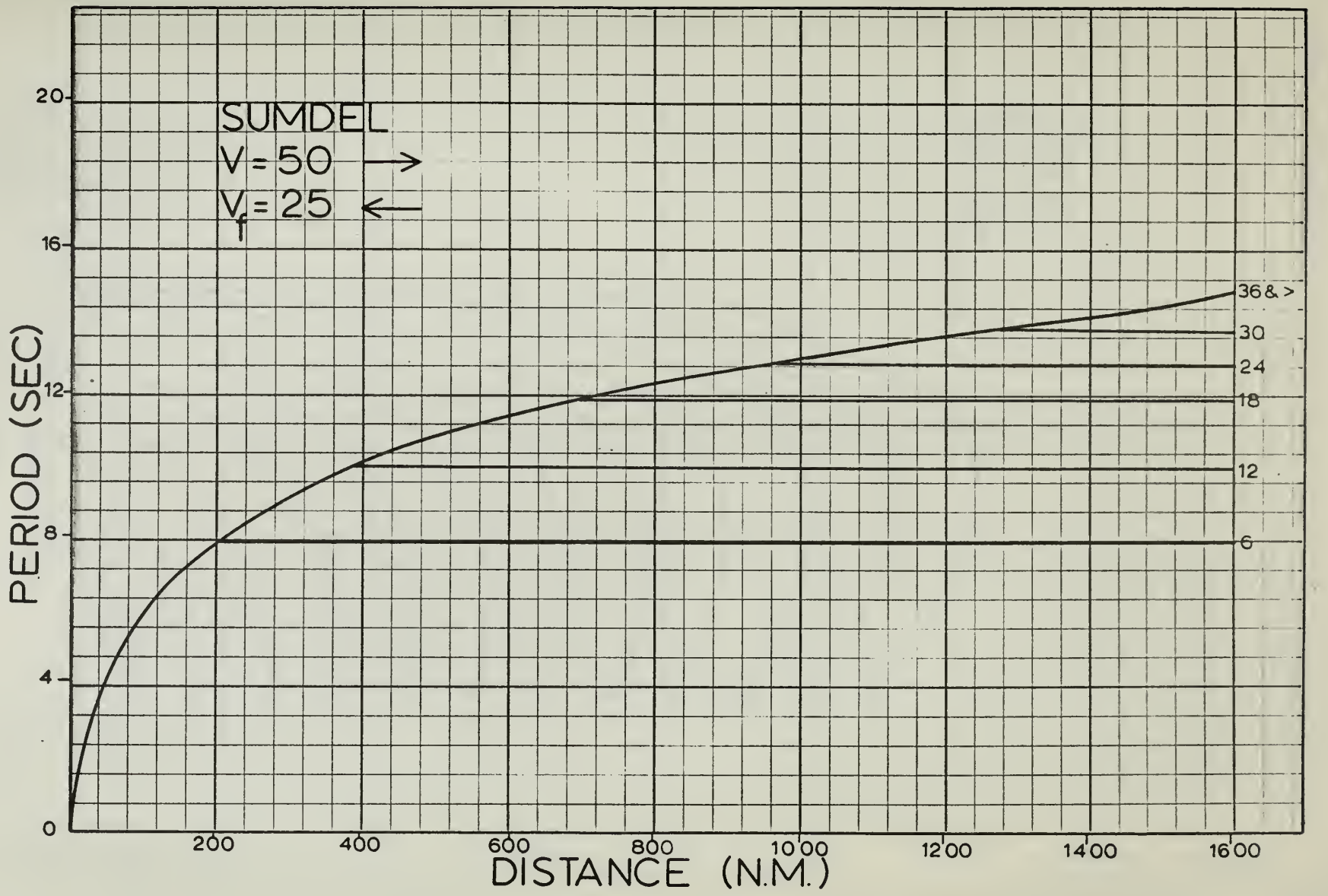



SUMDEL
V=50 →
V_f=20 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
42 &>
36
30
24
18
12
6

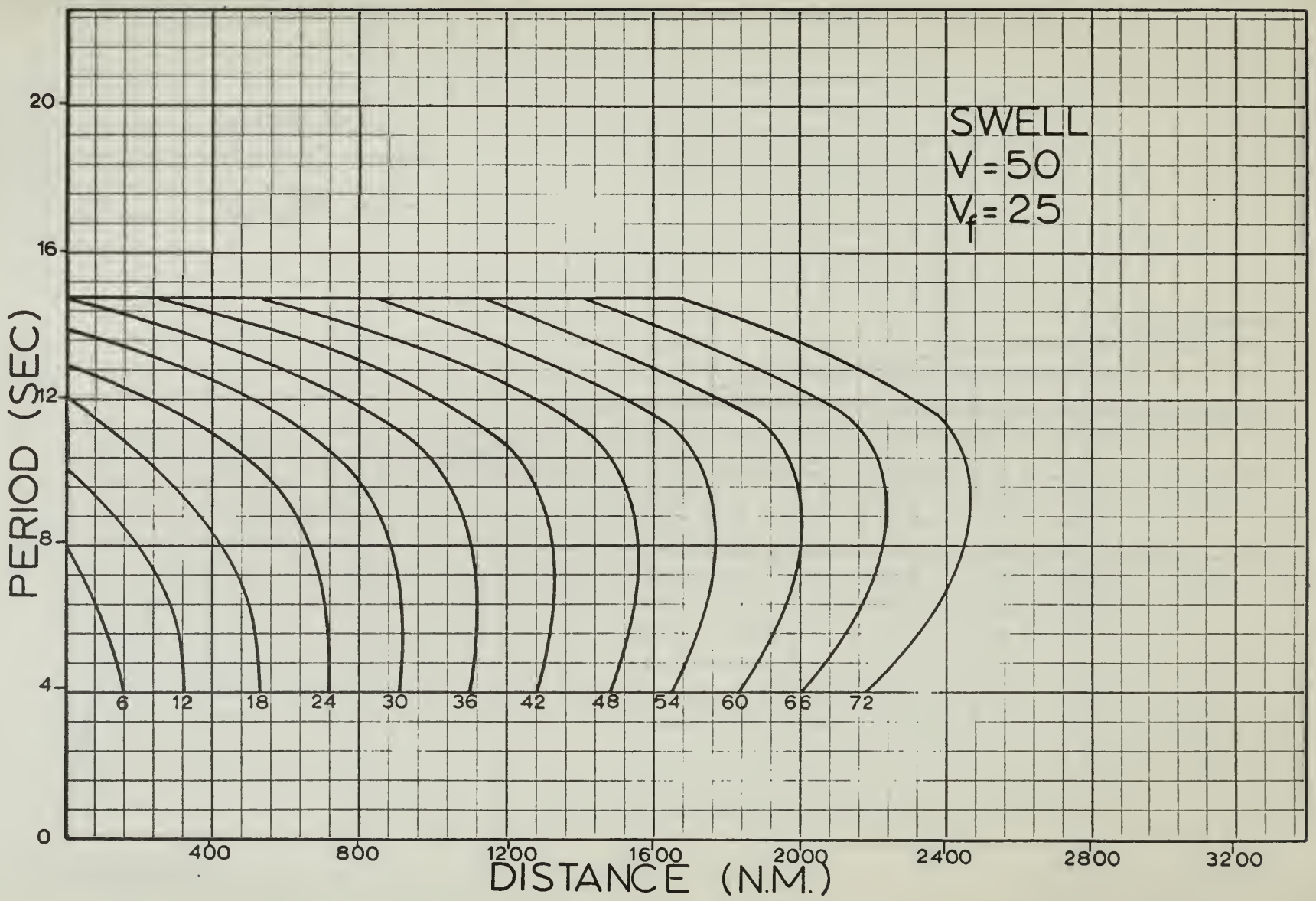



SWELL
V=50 →
Vf=20 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

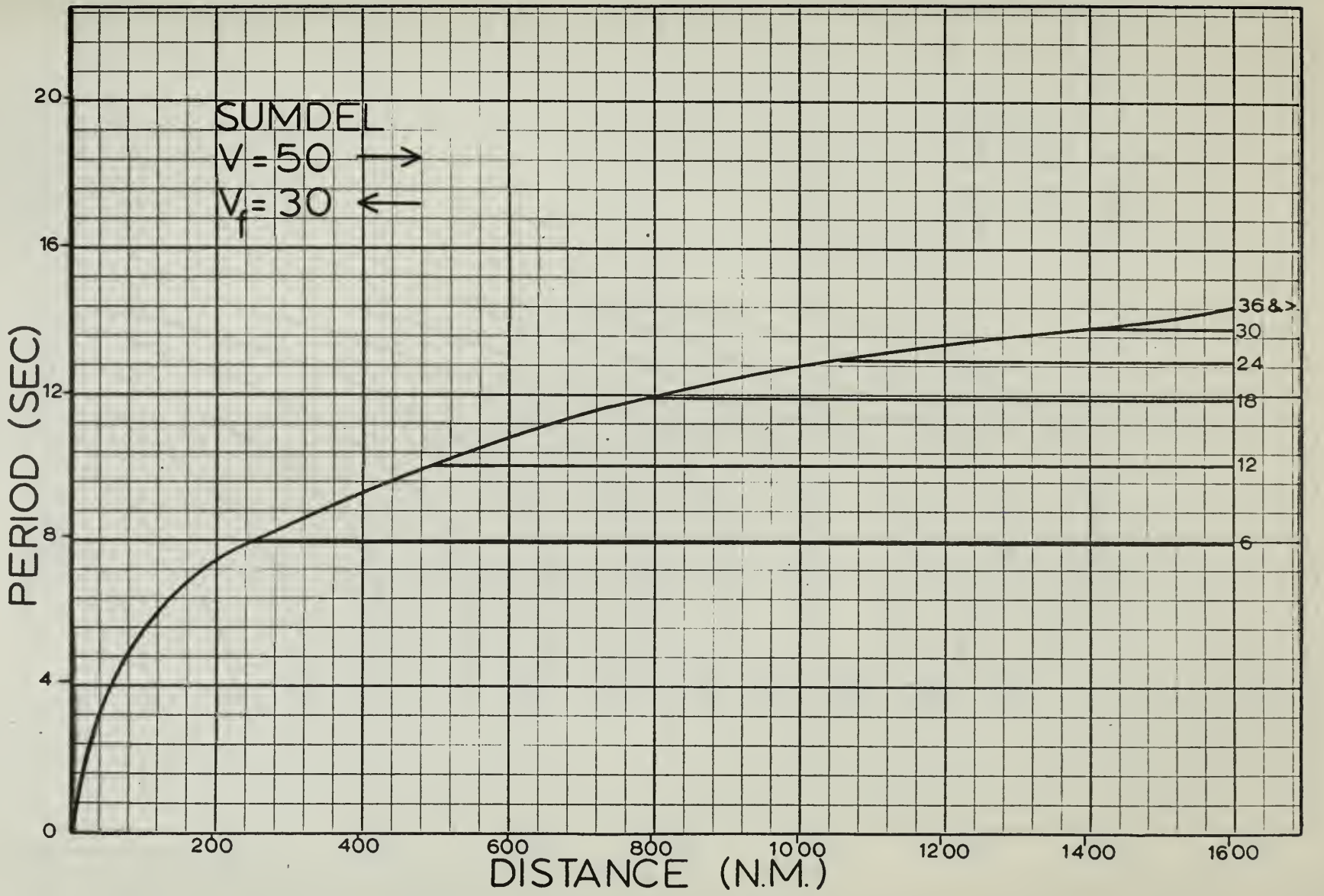



SUMDEL
V = 50 →
V_f = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36 & >
30
24
18
12
6

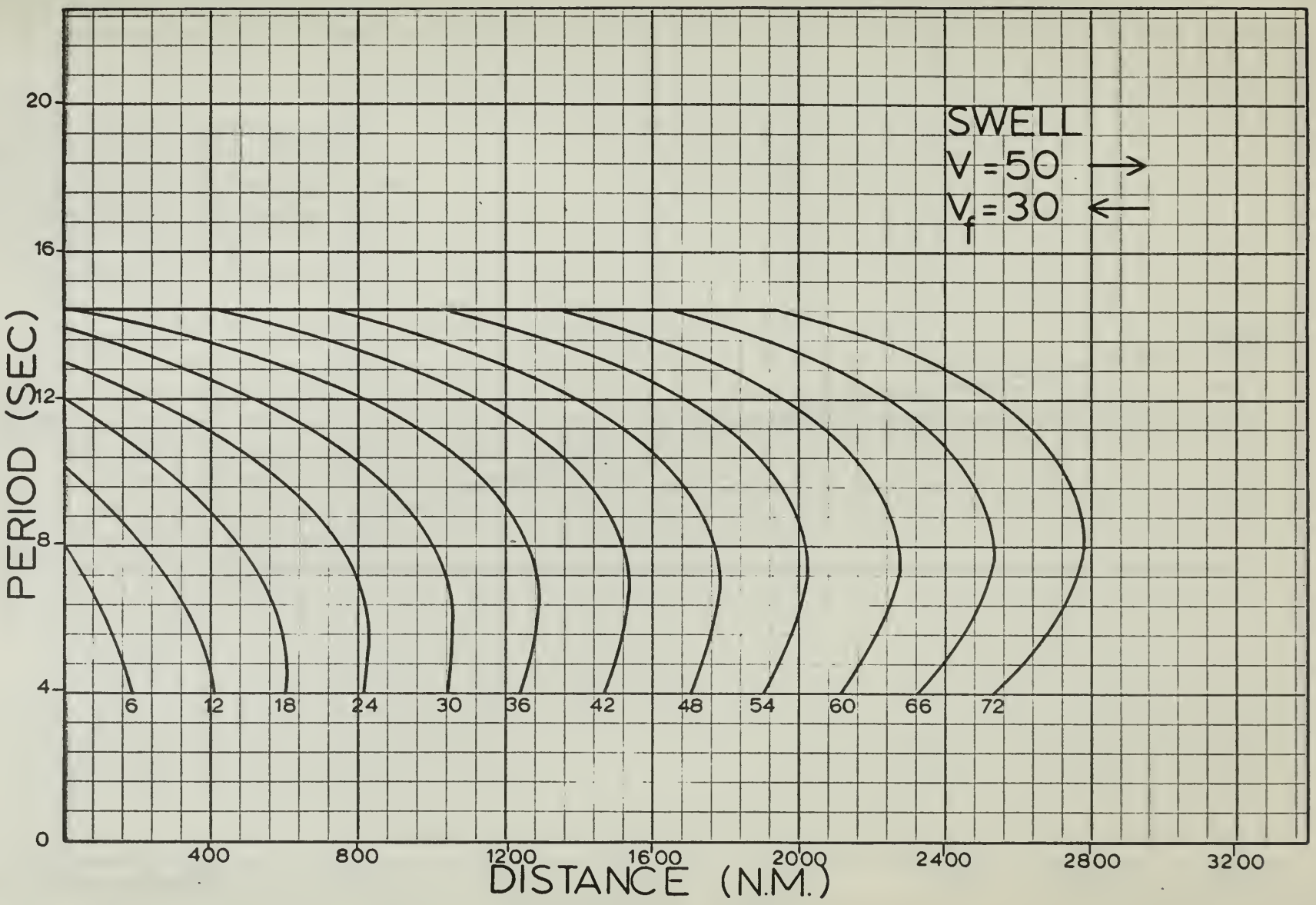



SWELL
V = 50
V_f = 25
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

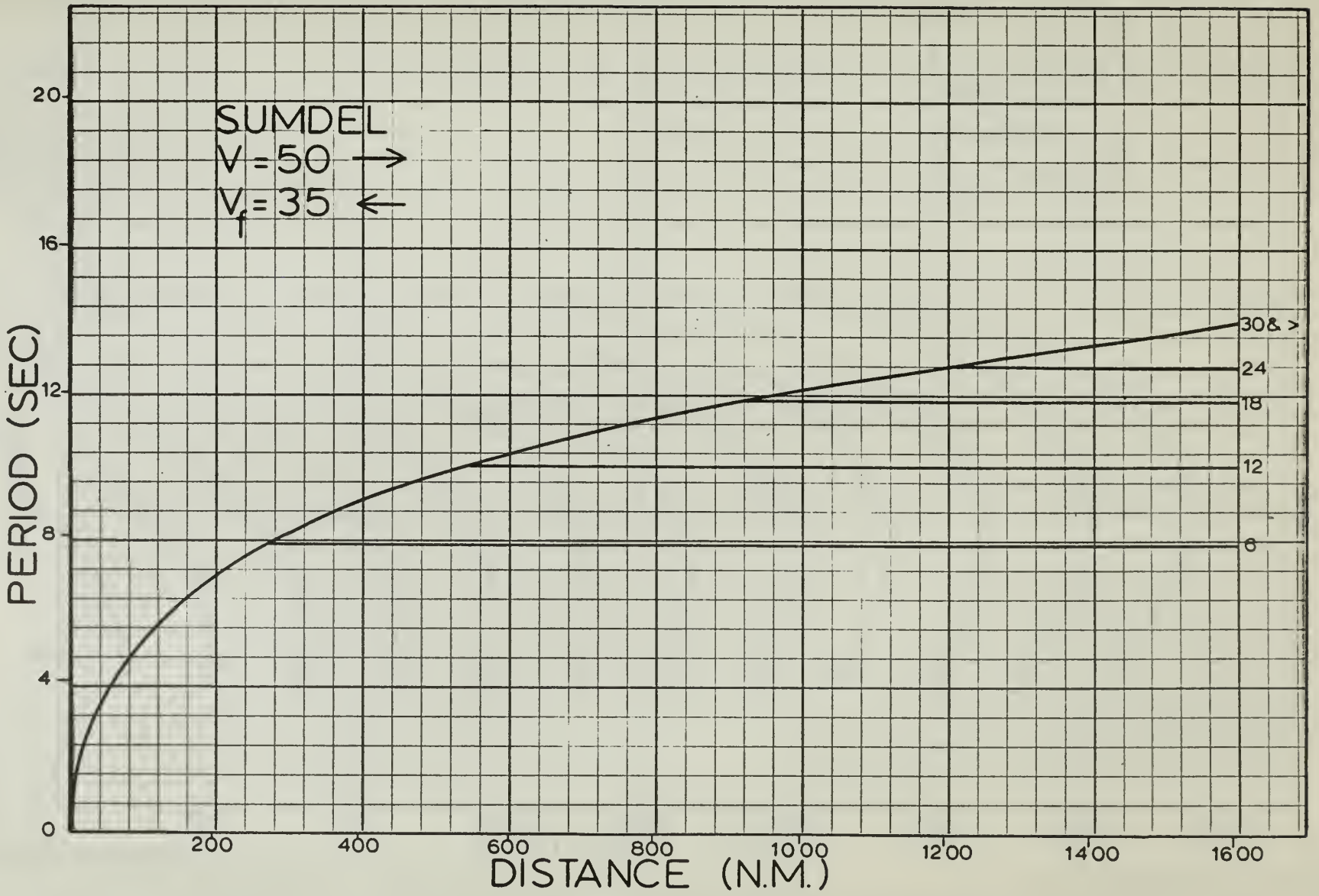



SUMDEL
V = 50 →
V_f = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36 &>
30
24
18
12
6

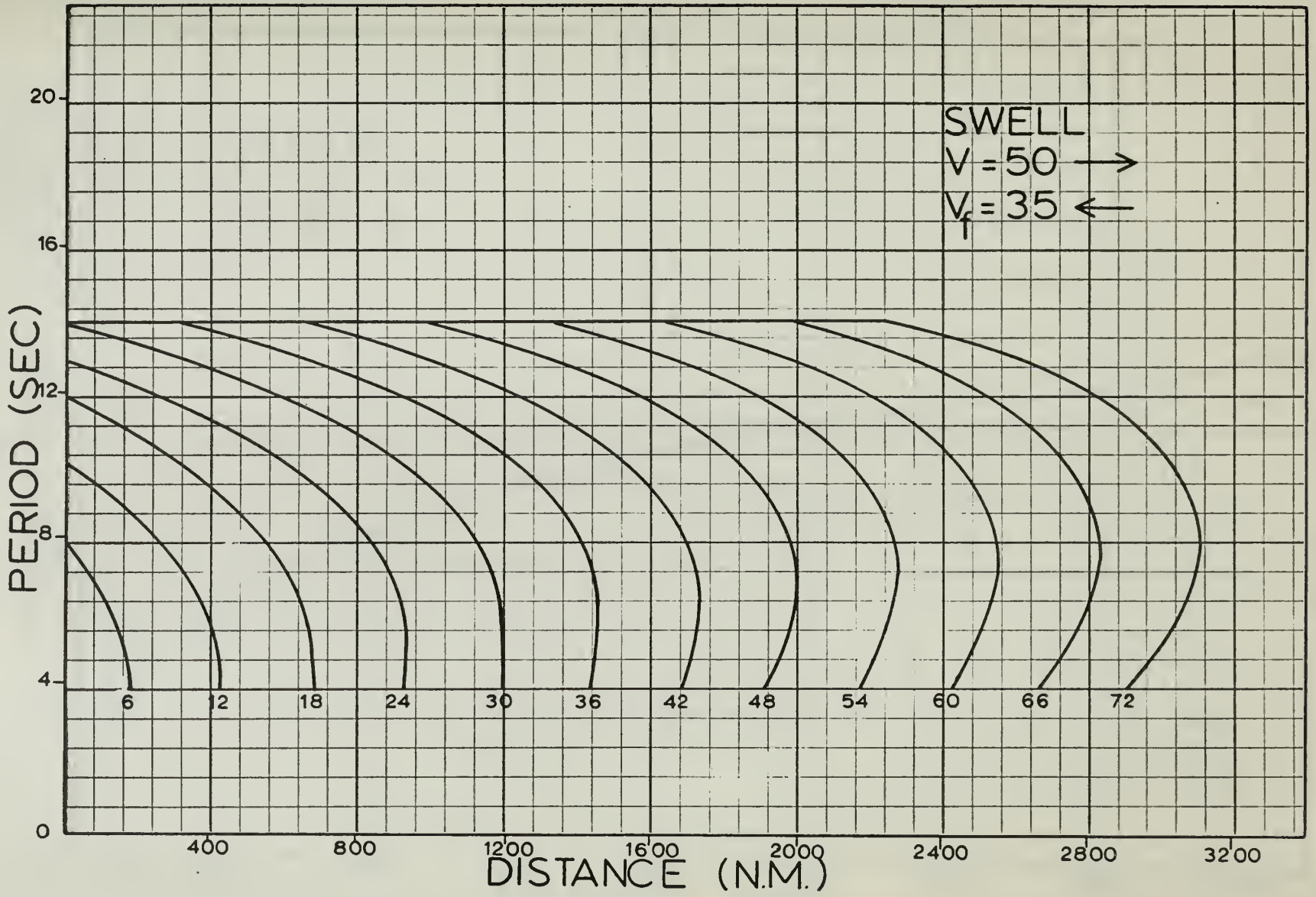



SWELL
V = 50 →
V_f = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

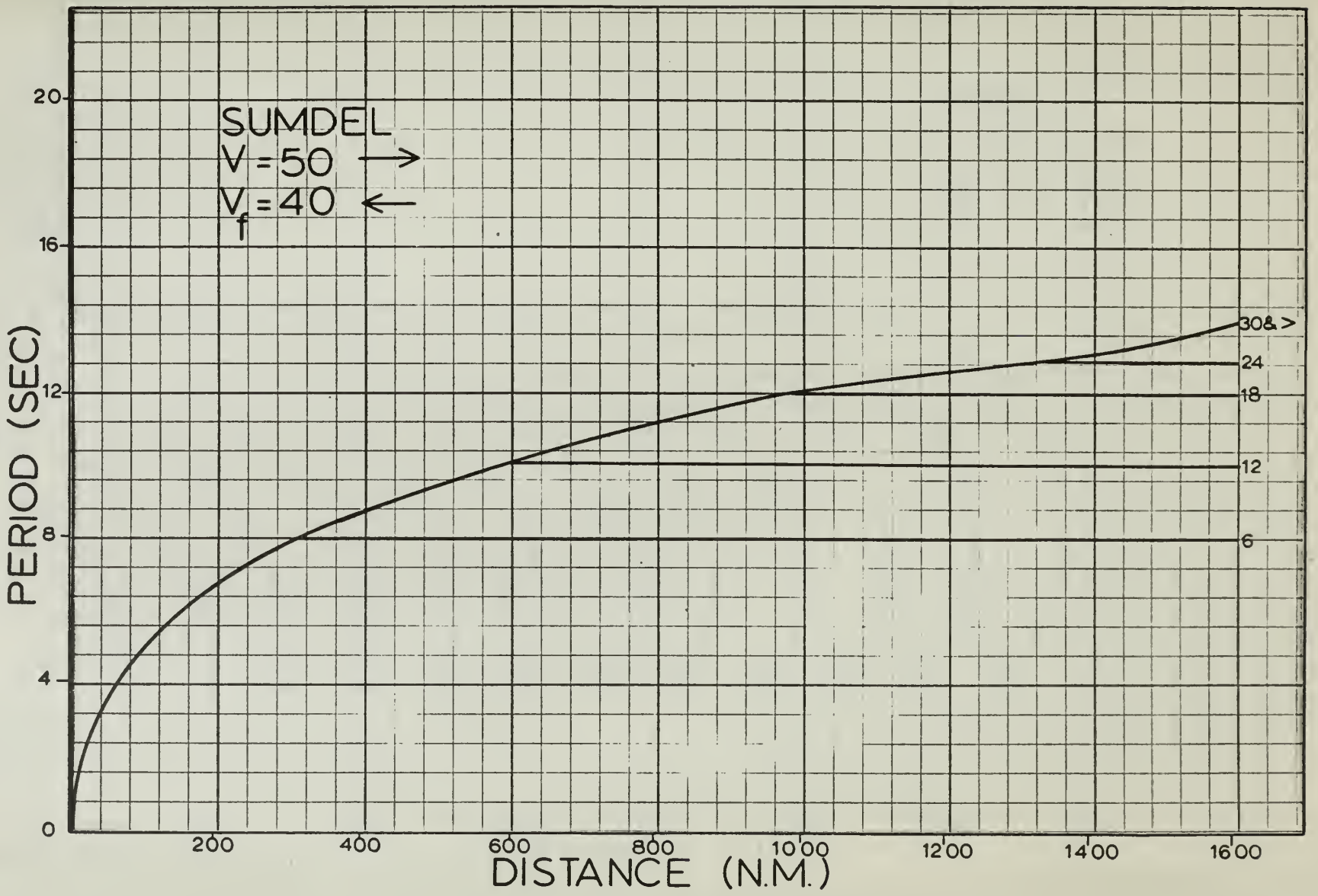



SUMDEL
V = 50 →
V_f = 35 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
30& >
24
18
12
6

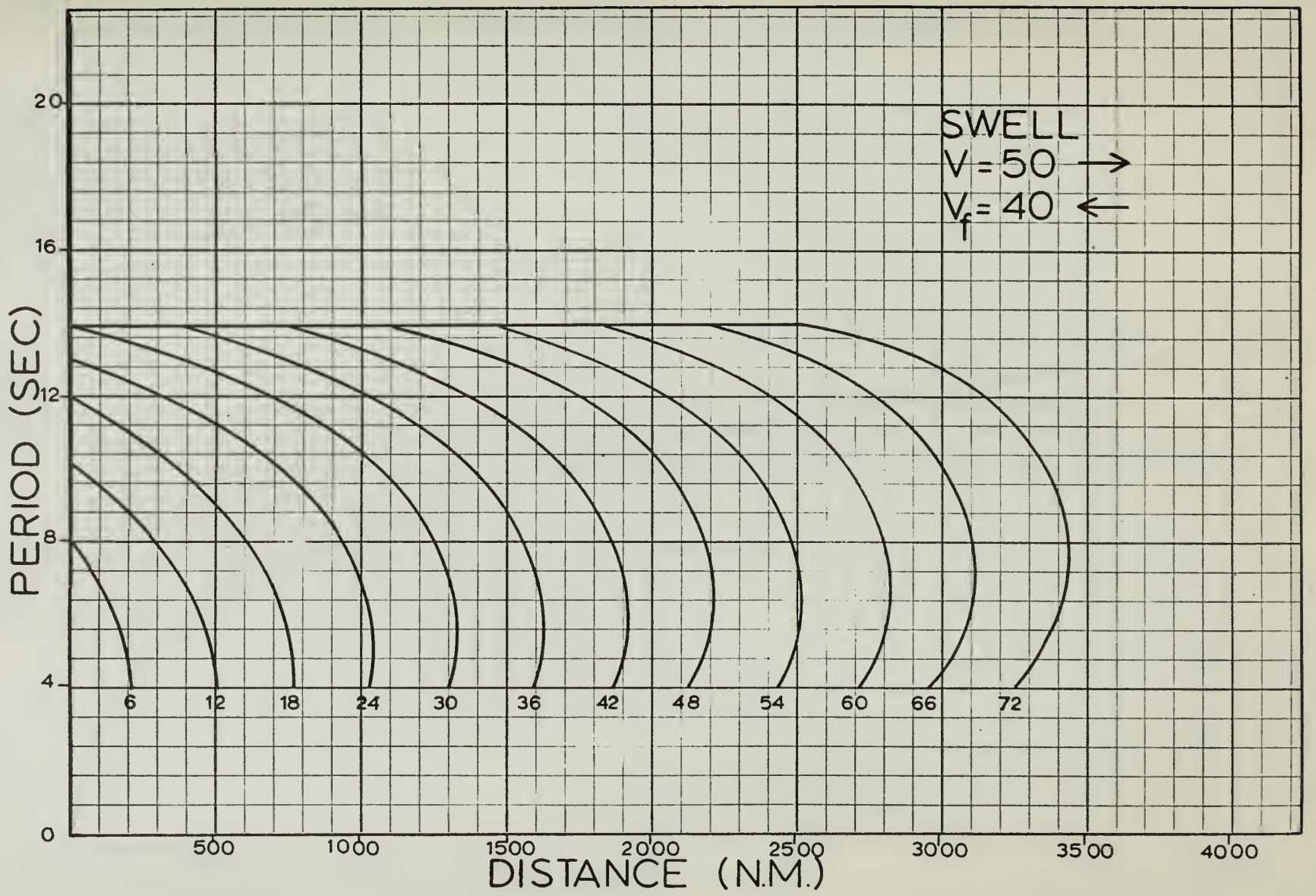



SWELL
V = 50 →
Vf = 35 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

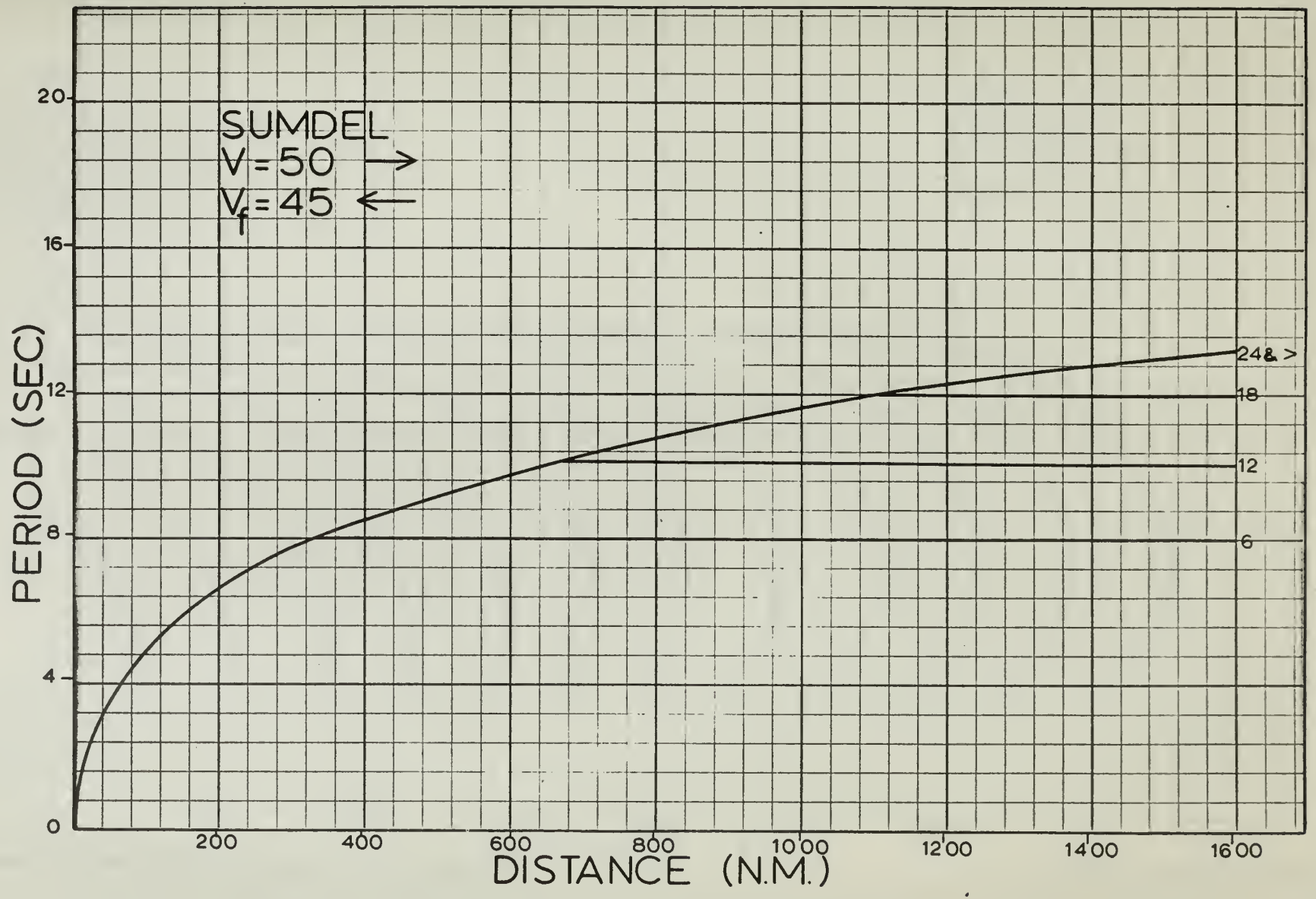



SUMDEL
V = 50 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
30& >
24
18
12
6

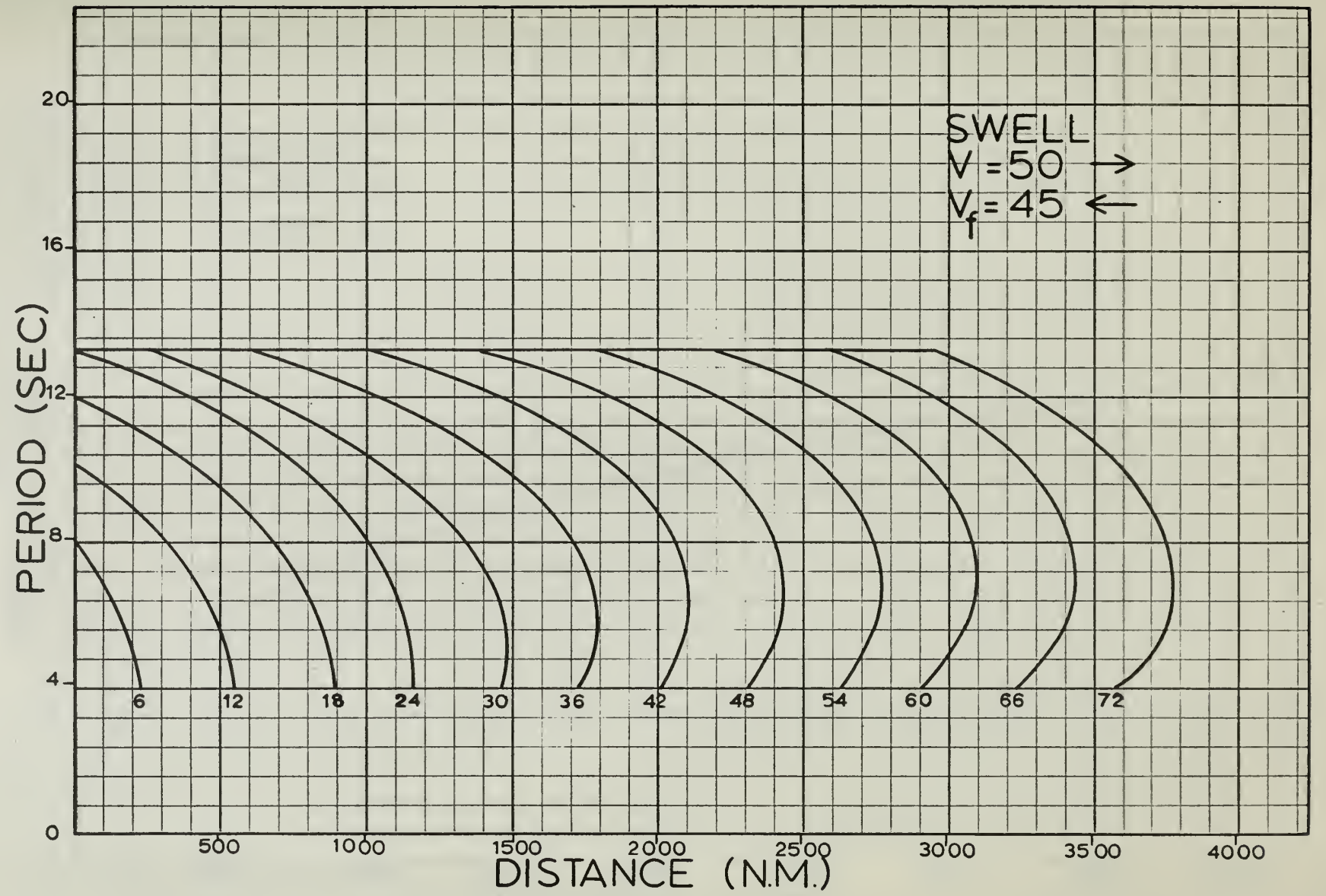



SWELL
V = 50 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE (N.M.)

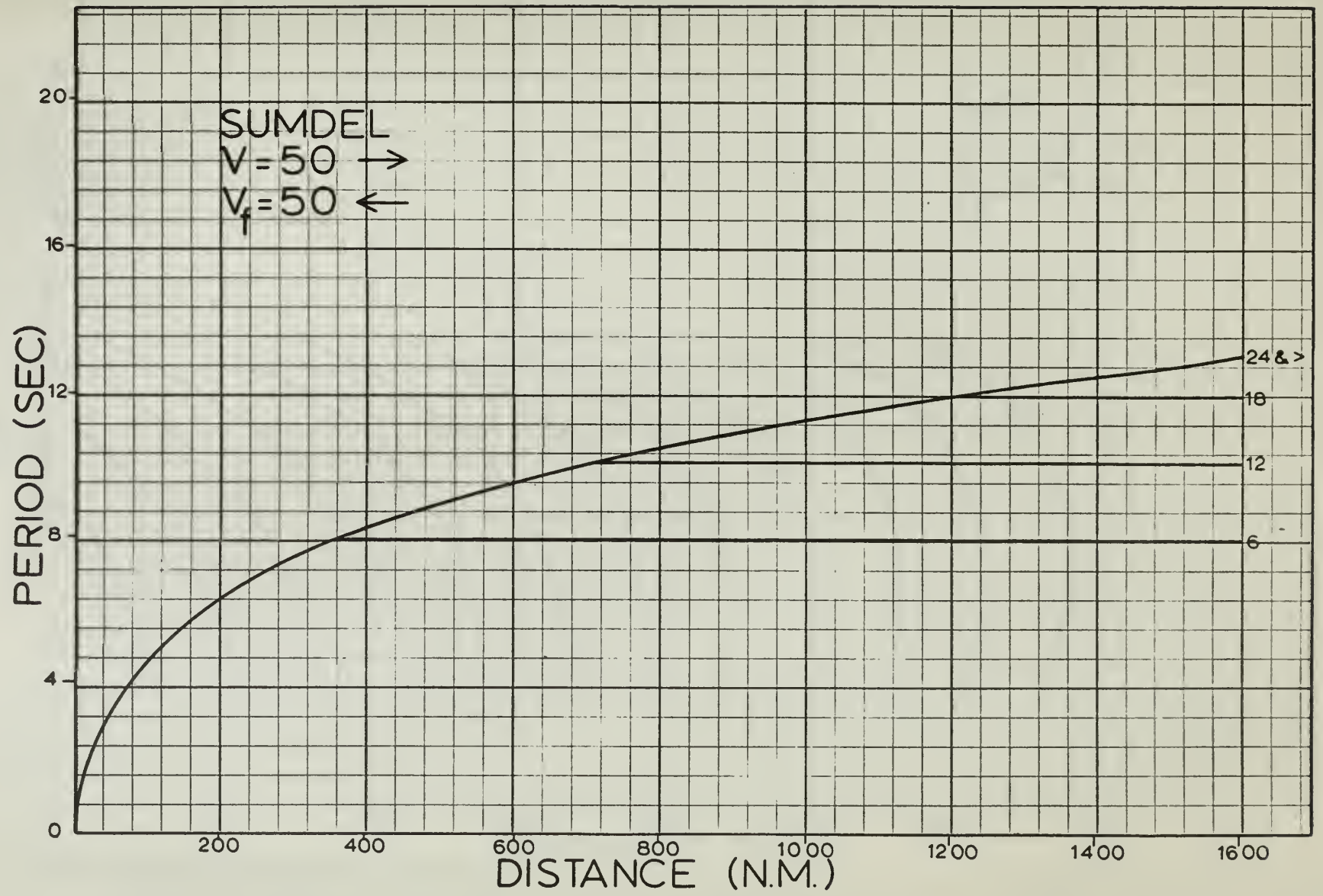



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V_f = 45 ←
PERIOD (SEC)
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1200
1400
1600
DISTANCE (N.M.)
24&>
18
12
6

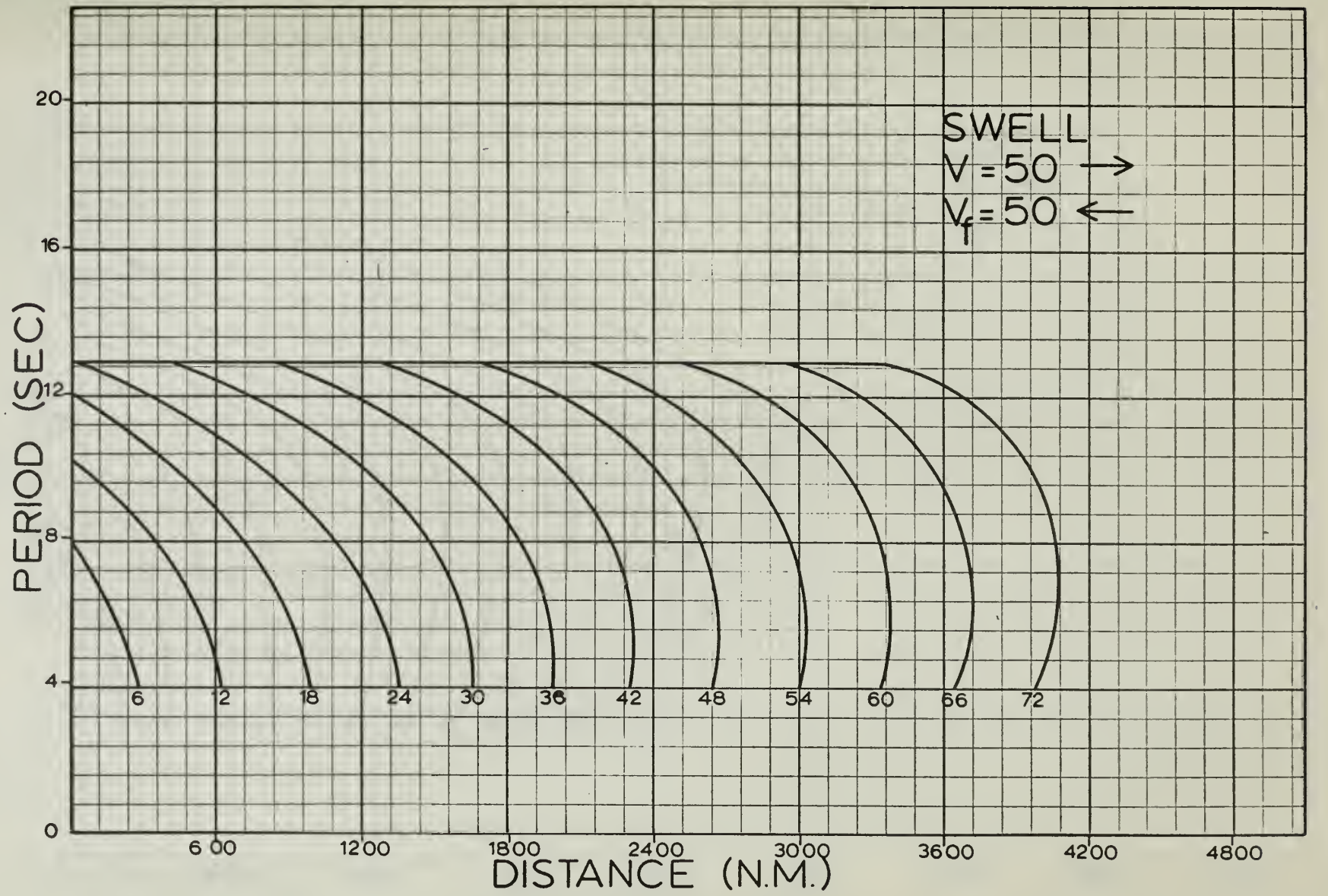



SWELL
V = 50 →
V_f = 45 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE (N.M.)

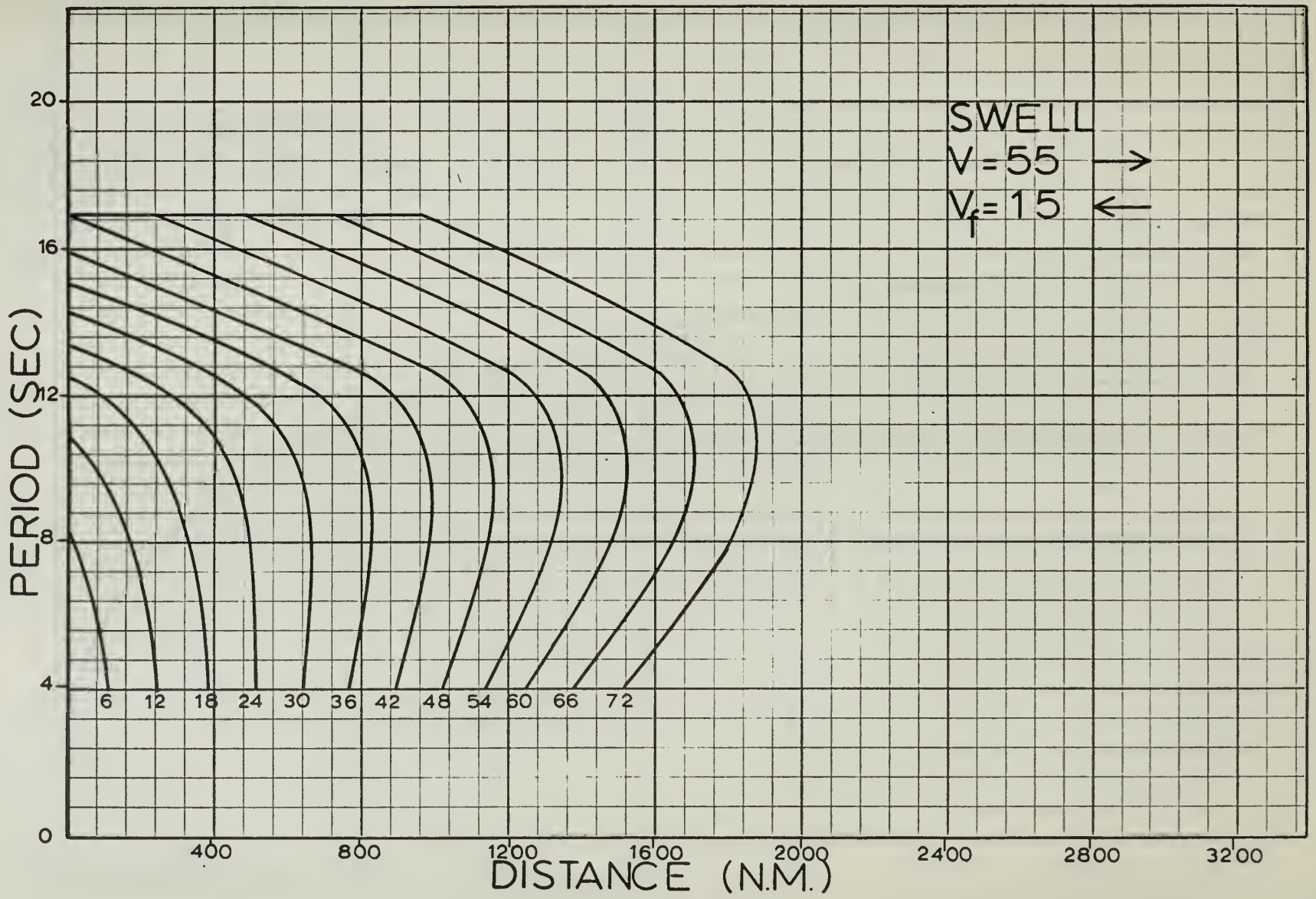



SUMDEL
V = 50 →
V_f = 50 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
24 & >
18
12
6

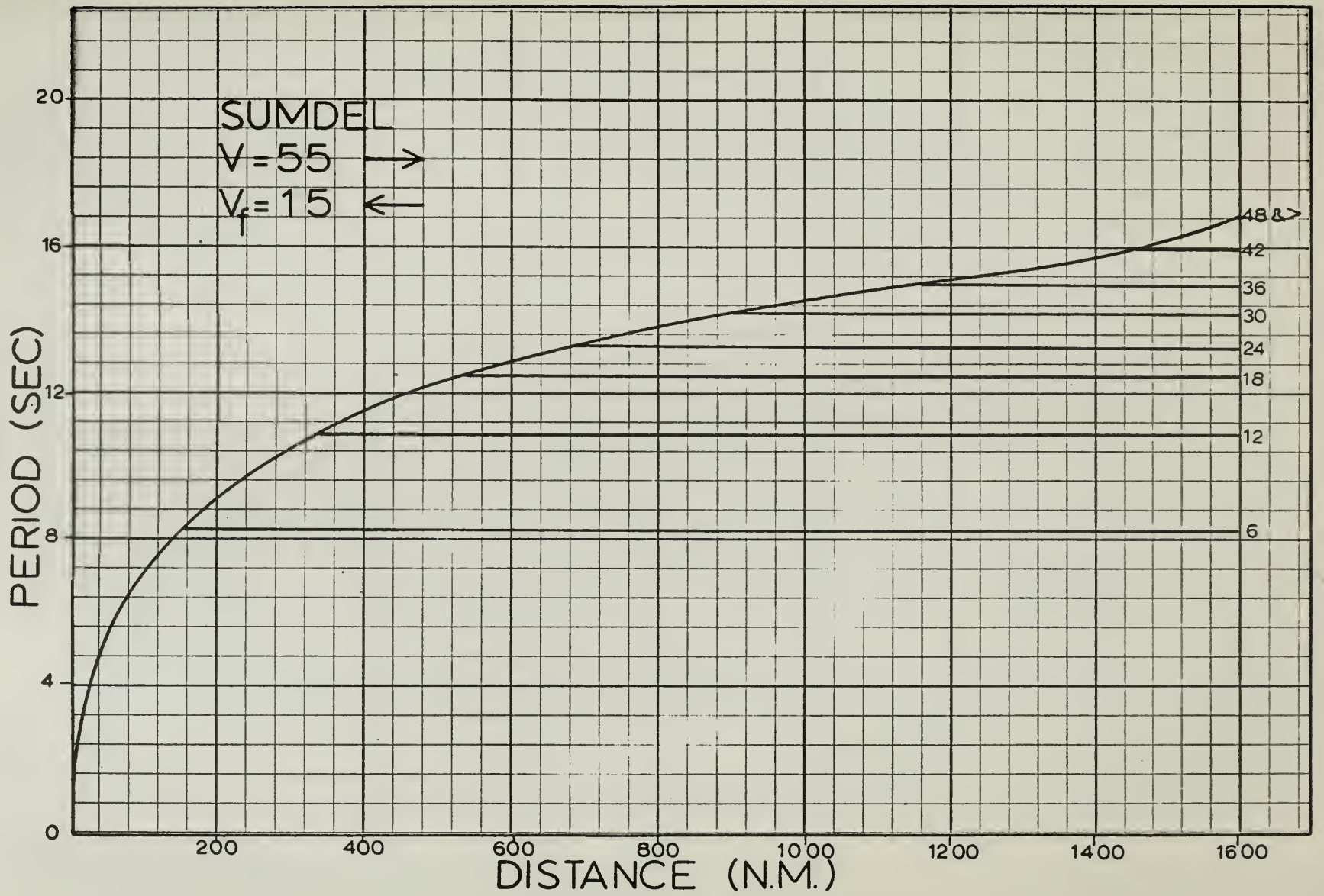



SWELL
V = 50 →
Vf = 50 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
600
1200
1800
2400
3000
3600
4200
4800
DISTANCE (N.M.)

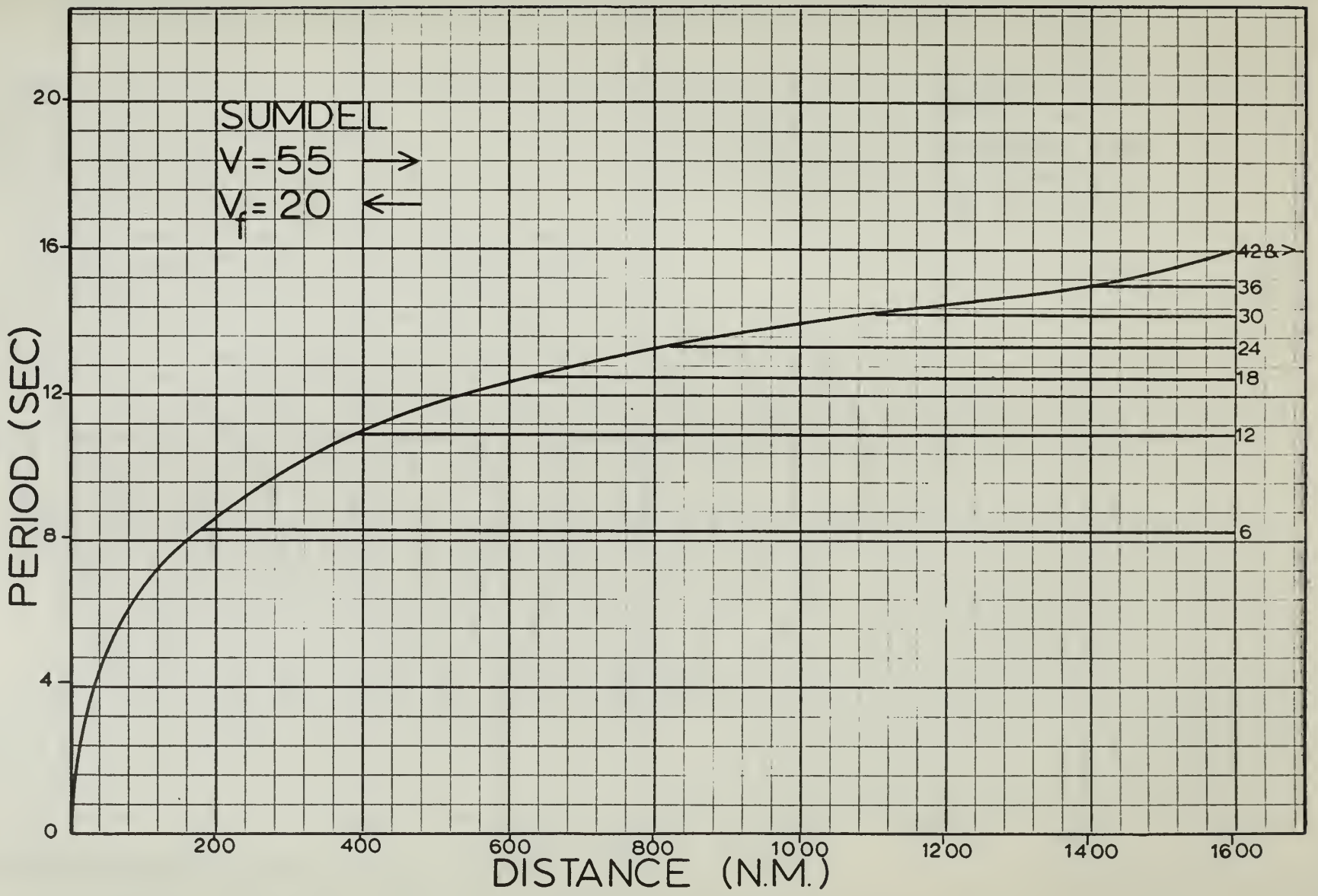



SWELL
V = 55 →
Vf = 15 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

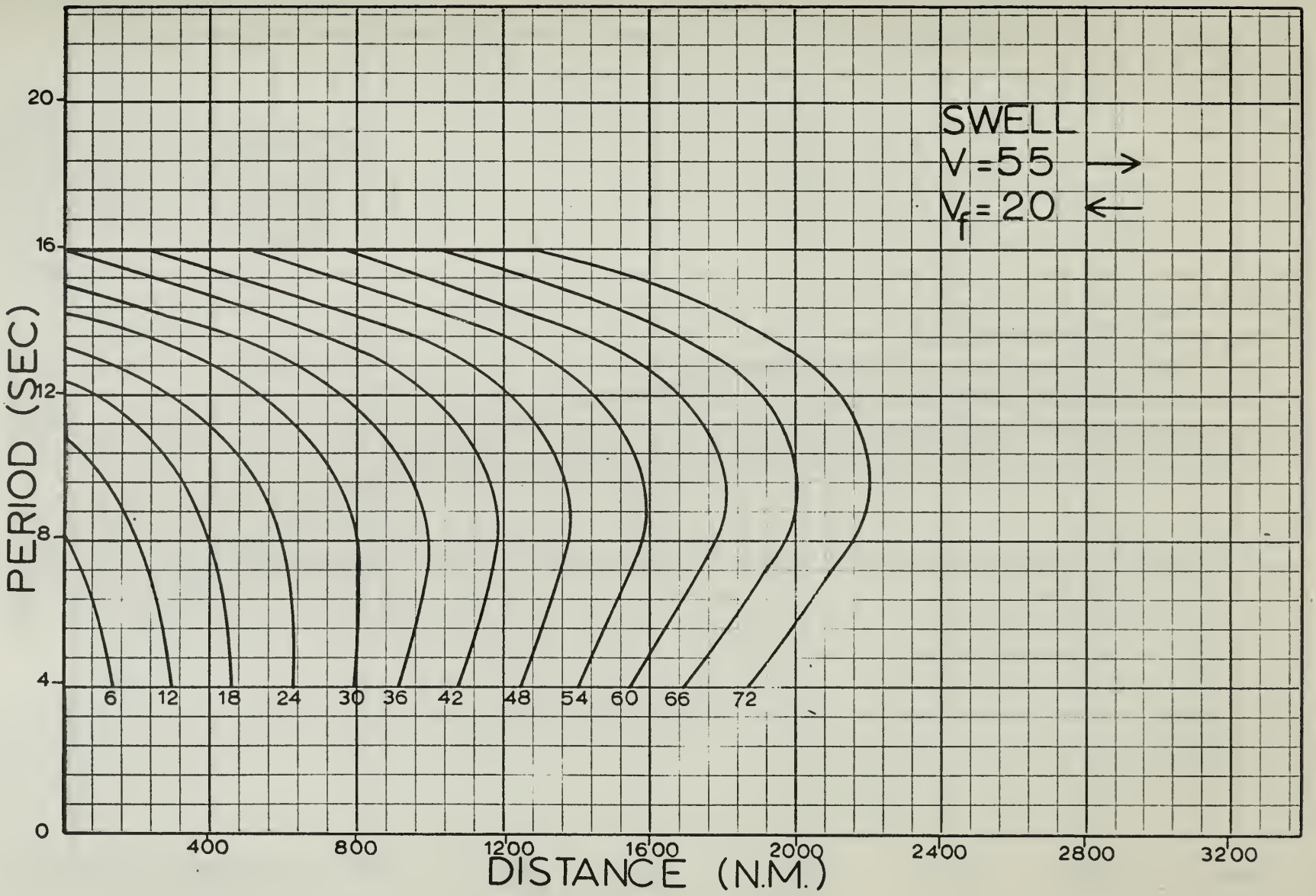



SUMDEL
V=55 →
Vf=15 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
48 &>
42
36
30
24
18
12
6

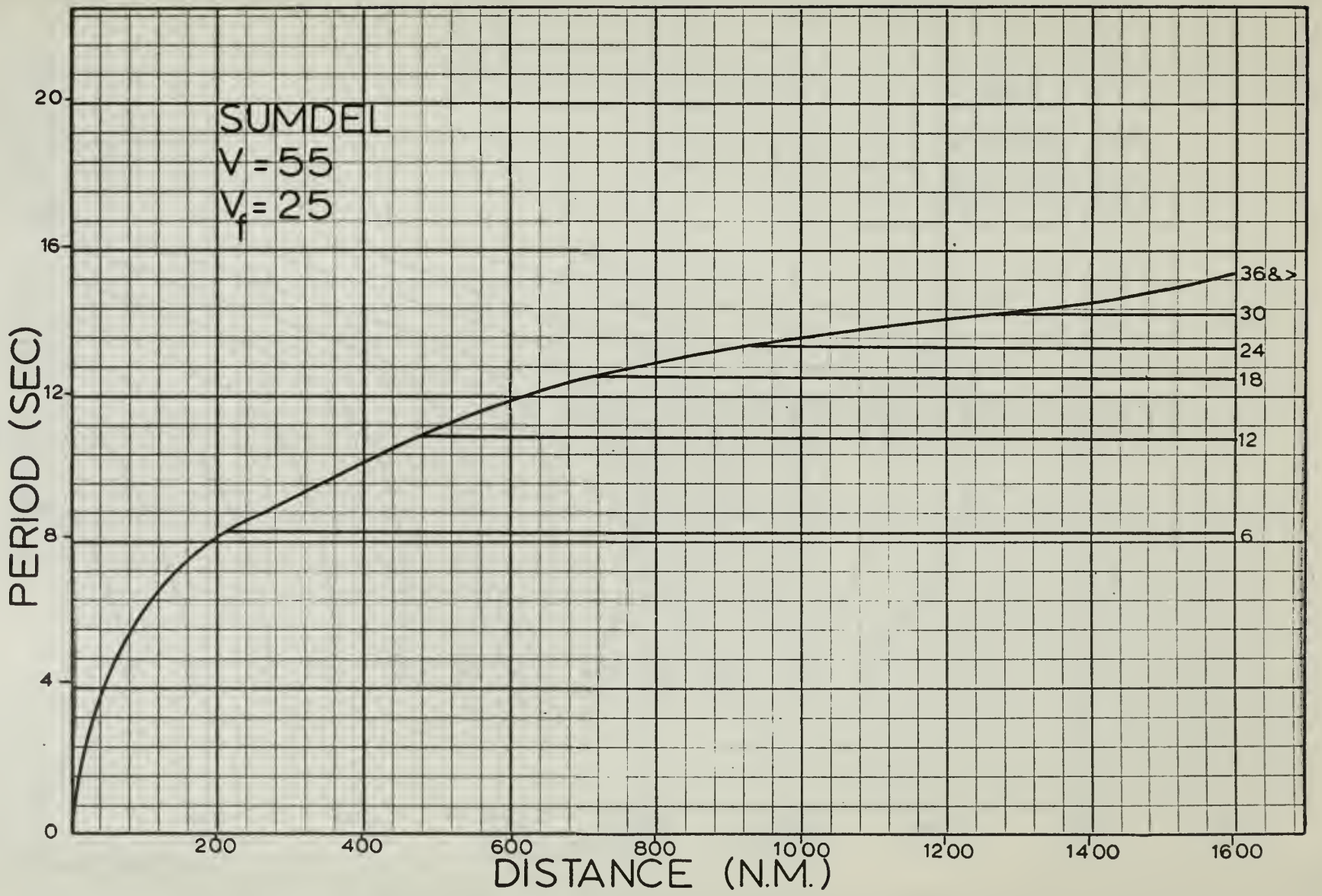


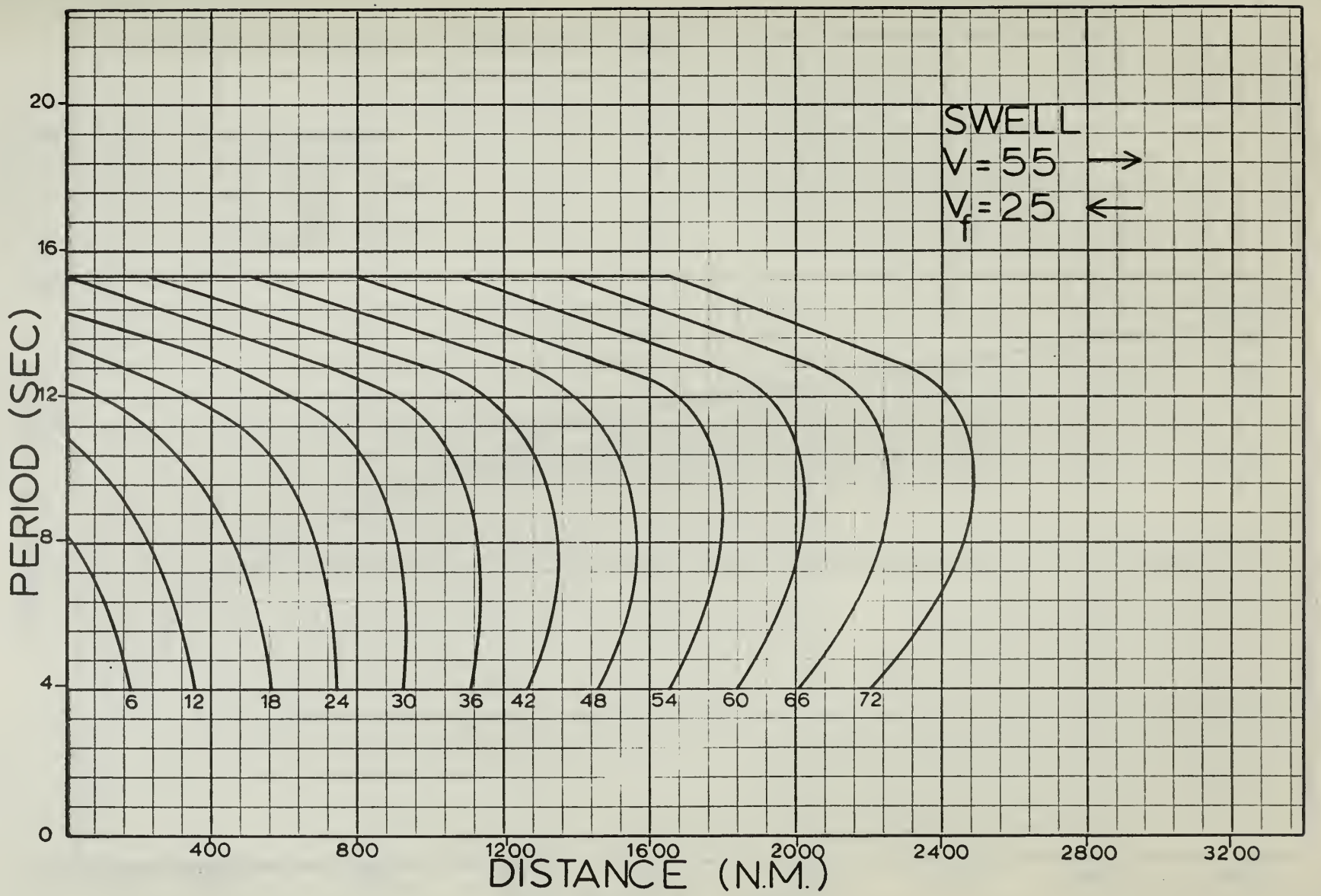

SUMDEL
V = 55 →
V_f = 20 ←
PERIOD (SEC)
DISTANCE (N.M.)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
42&>
36
30
24
18
12
6



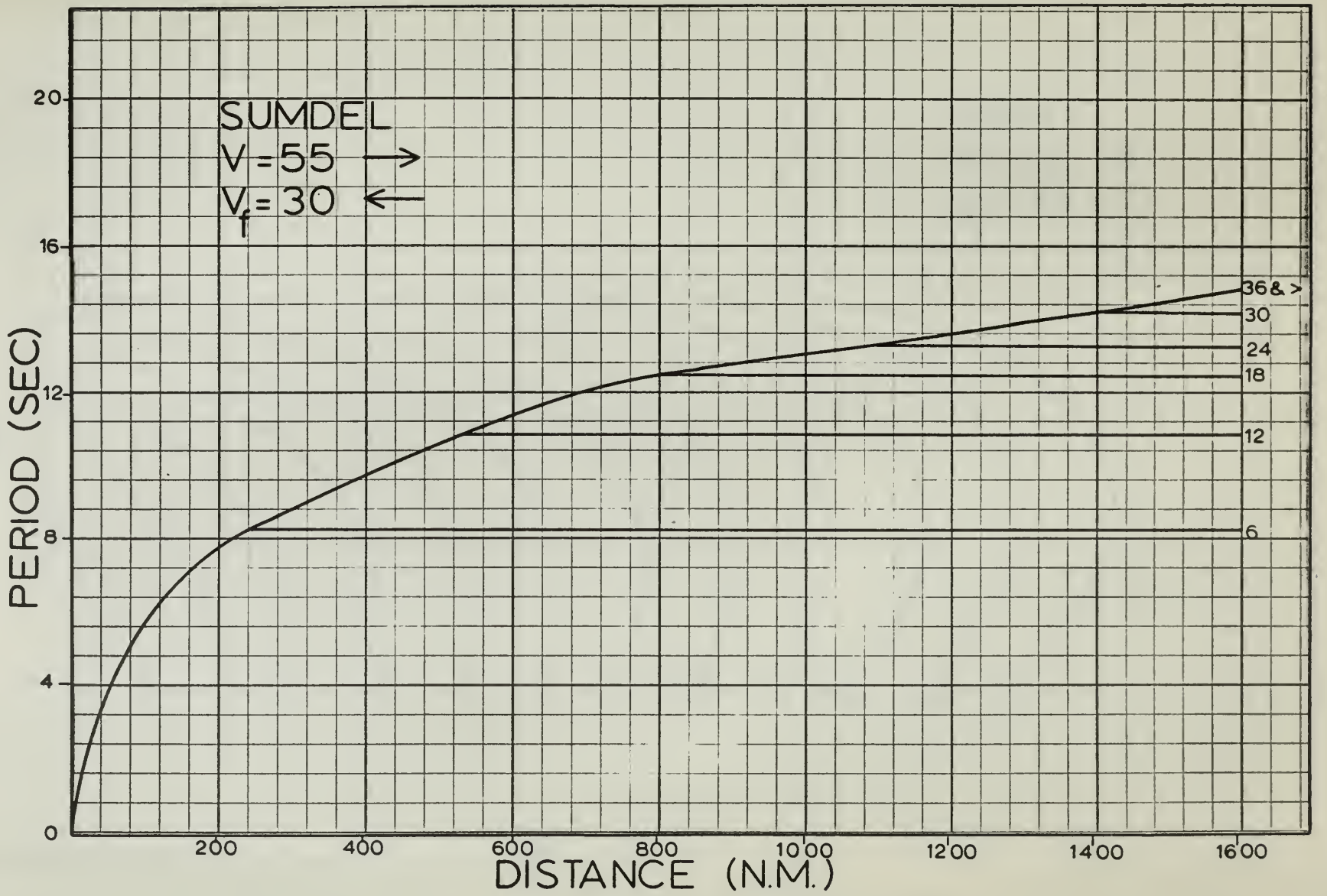

SWELL
V=55 →
V_f=20 ←
PERIOD (SEC)
20
16
12
8
4
0
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)



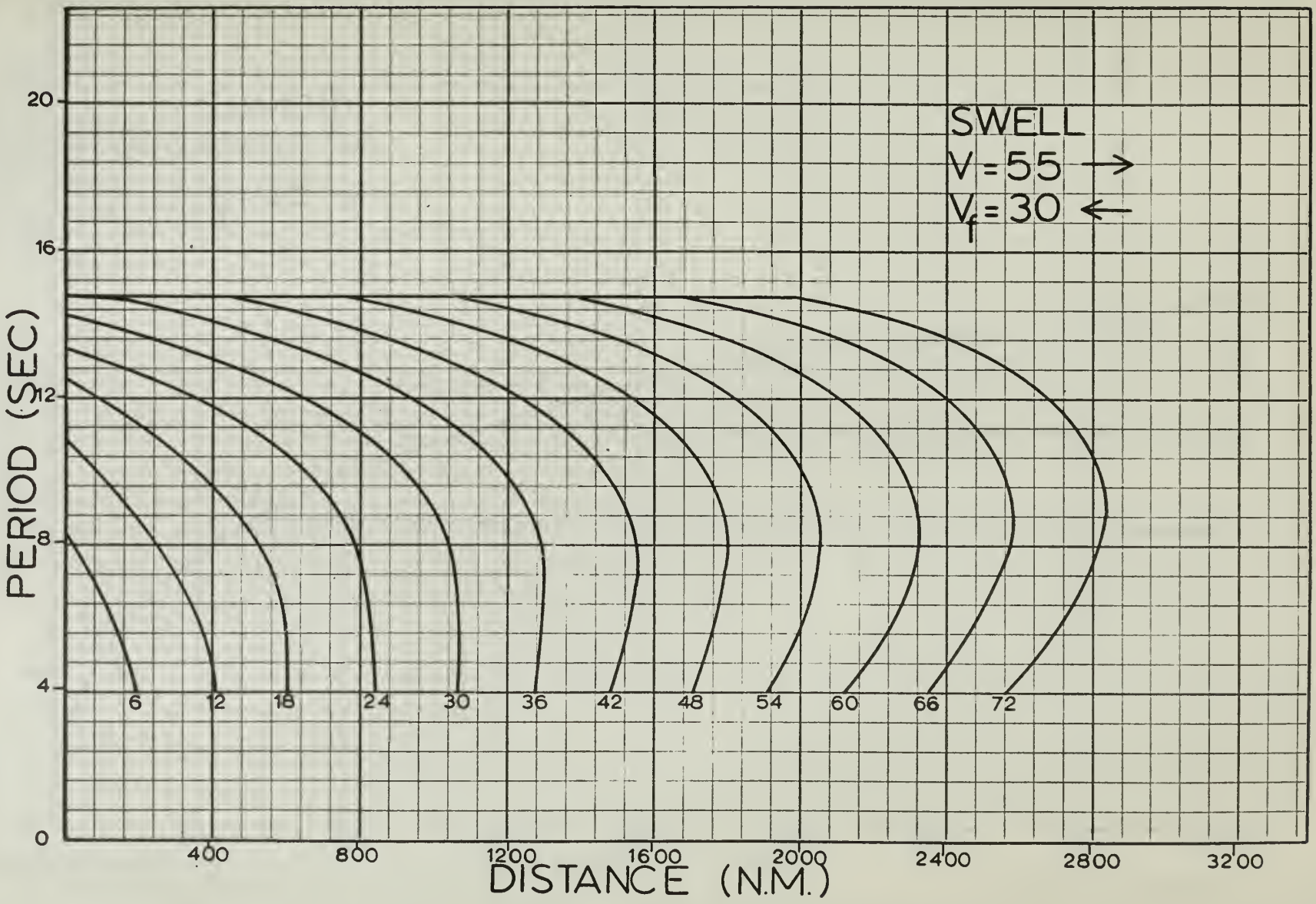

SUMDEL
V = 55
V_f = 25
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36&>
30
24
18
12
6


SWELL
V = 55 →
V_f = 25 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

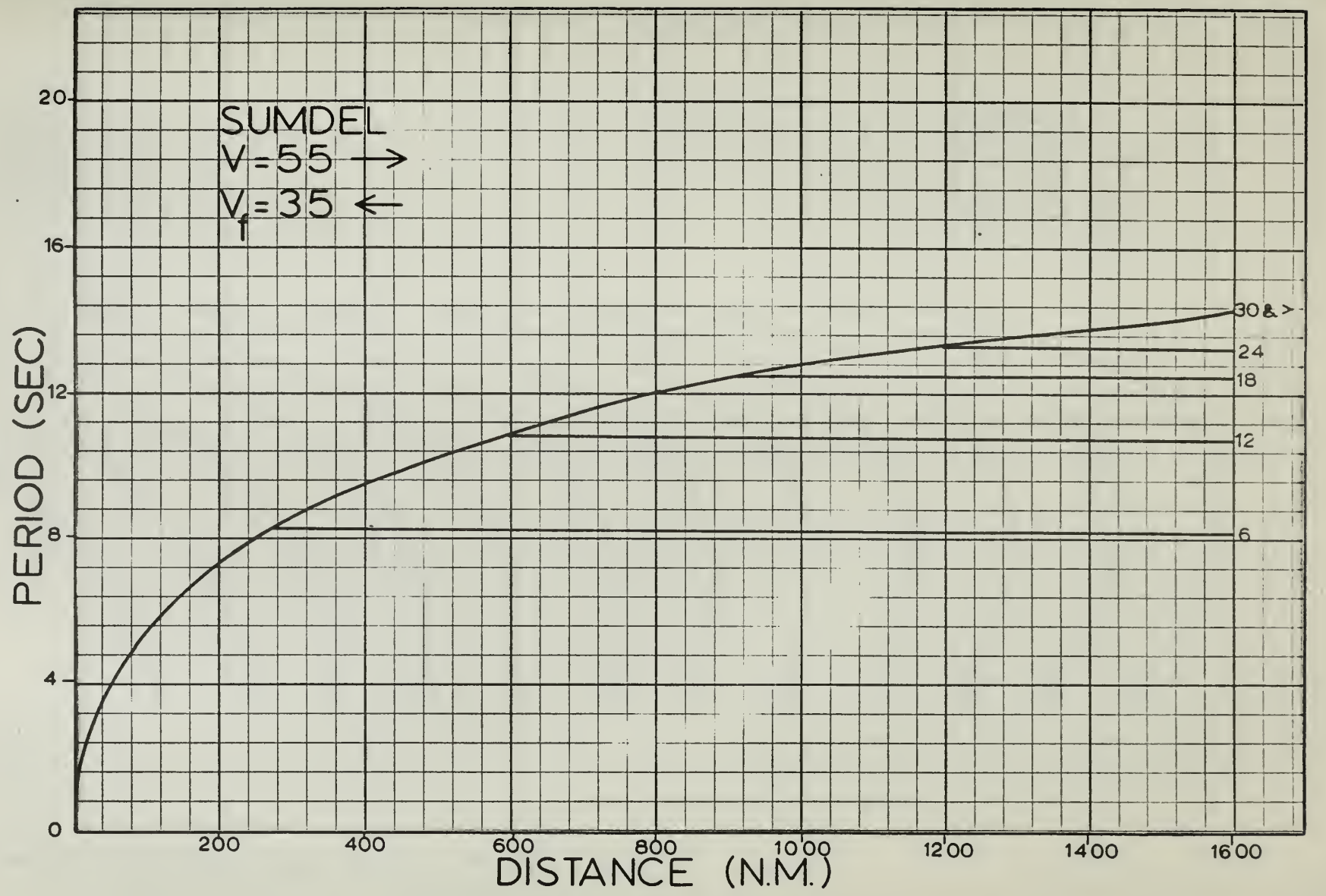



SUMDEL
V = 55 →
V_f = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
36 & >
30
24
18
12
6

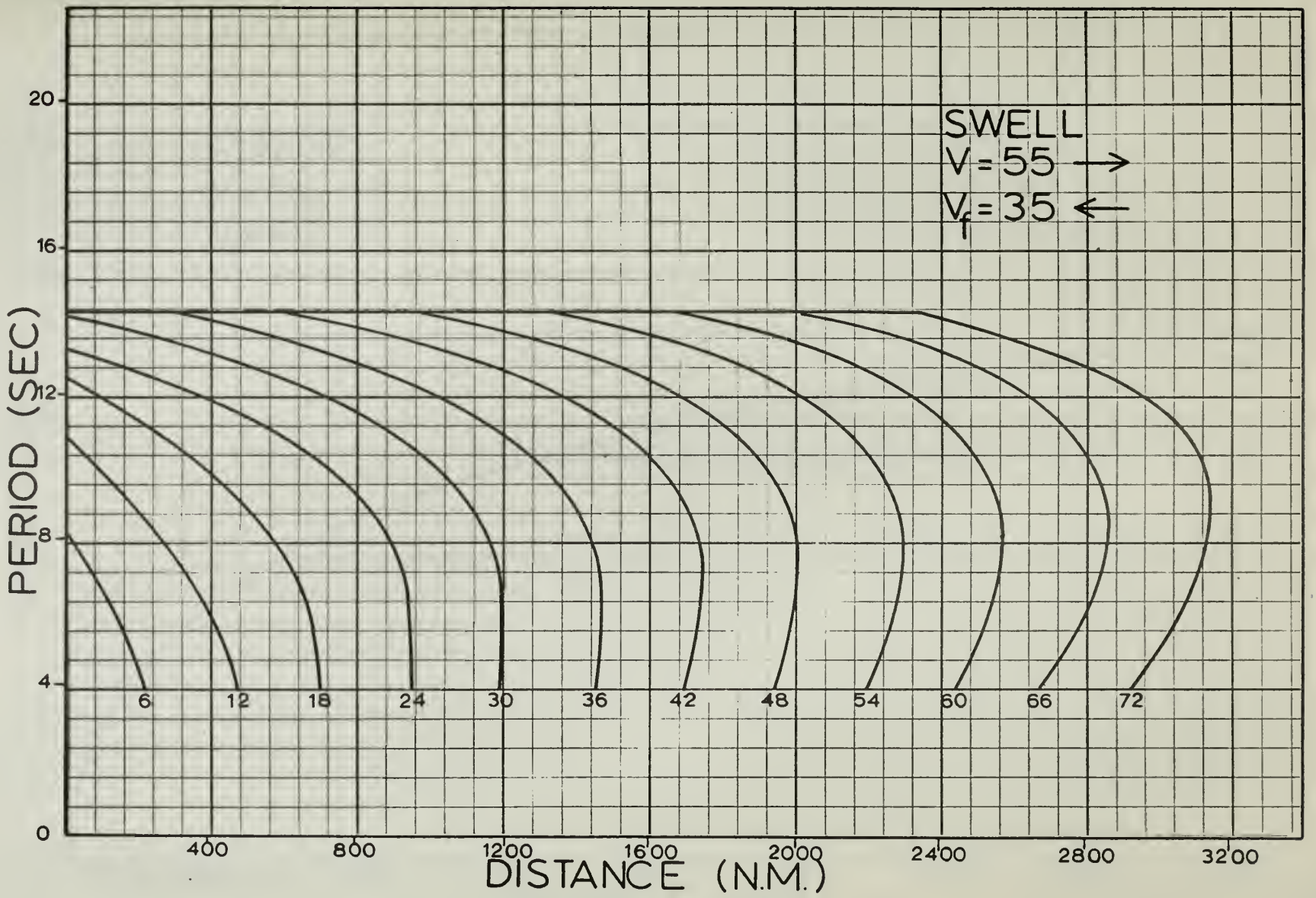



SWELL
V = 55 →
V_f = 30 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

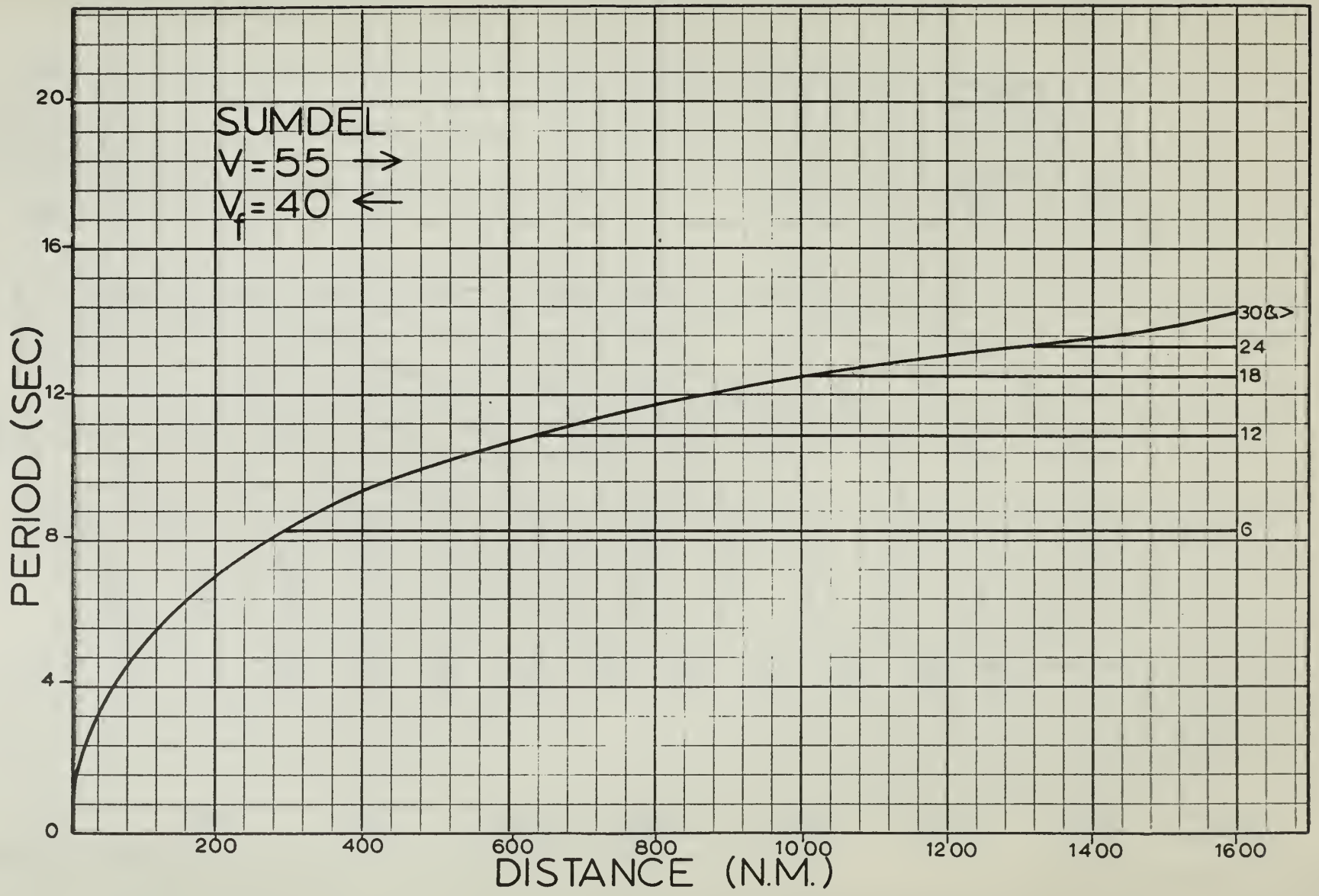



SUMDEL
V=55 →
V_f=35 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
30 & >
24
18
12
6

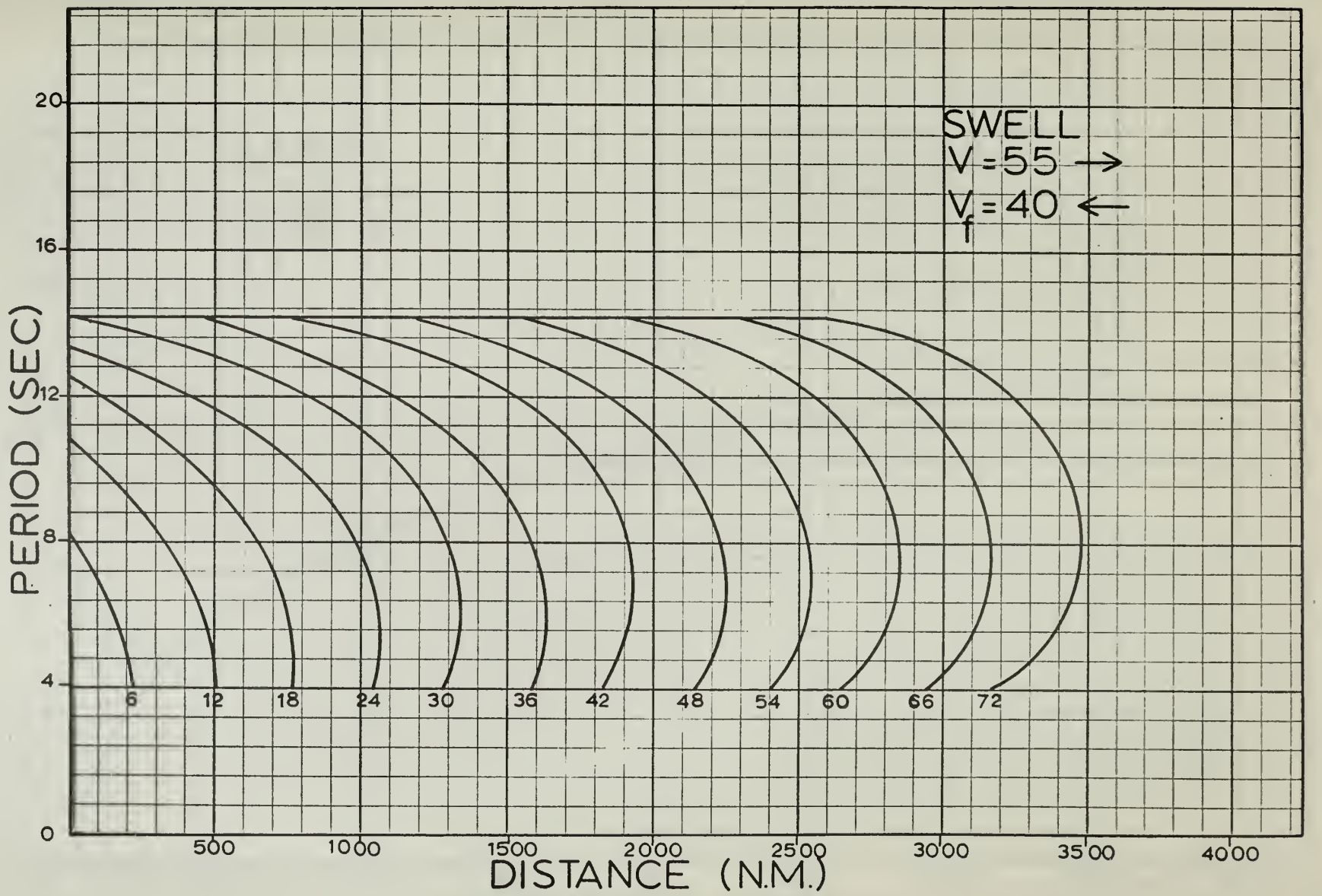



SWELL
V = 55 →
Vf = 35 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
400
800
1200
1600
2000
2400
2800
3200
DISTANCE (N.M.)

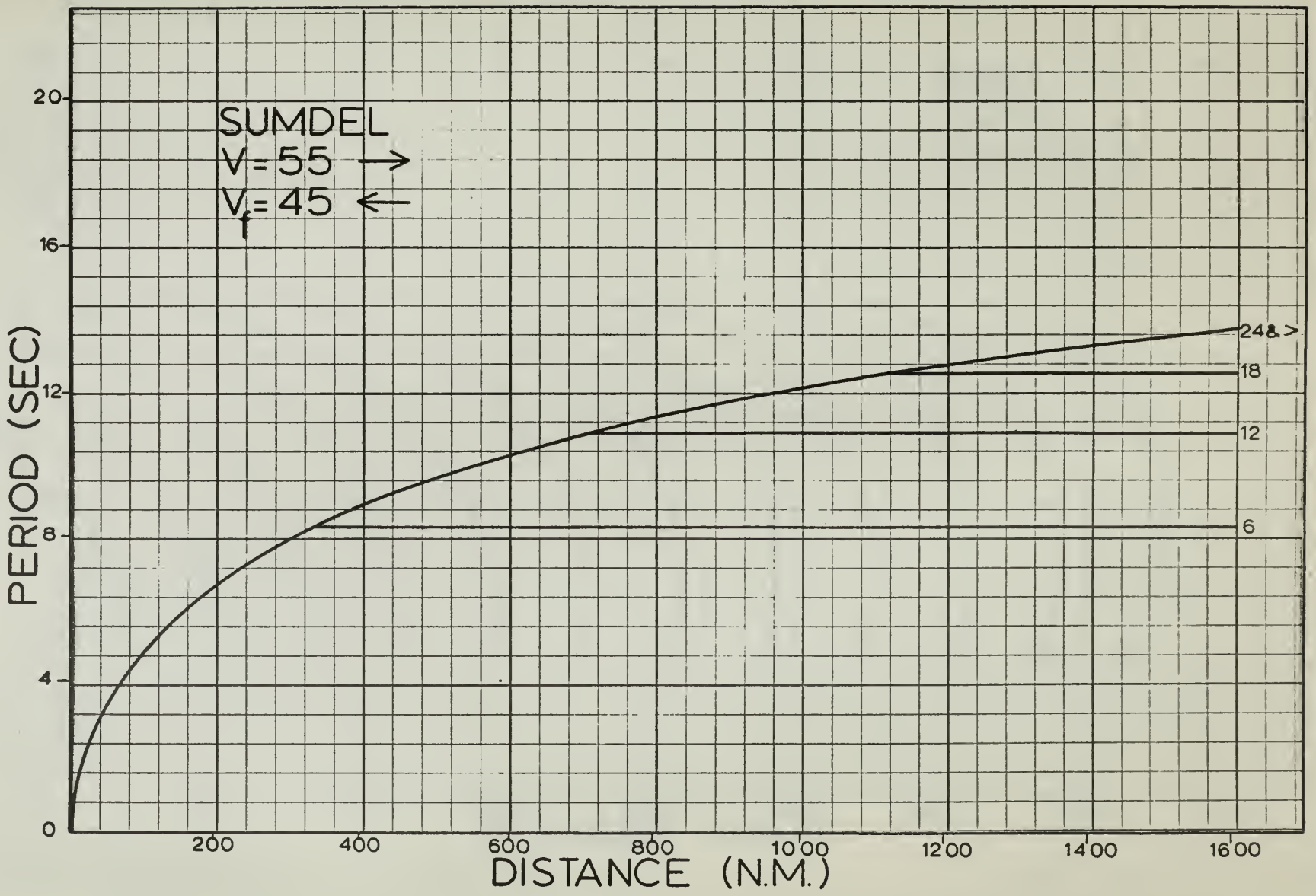



SUMDEL
V=55 →
Vf=40 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
30&>
24
18
12
6

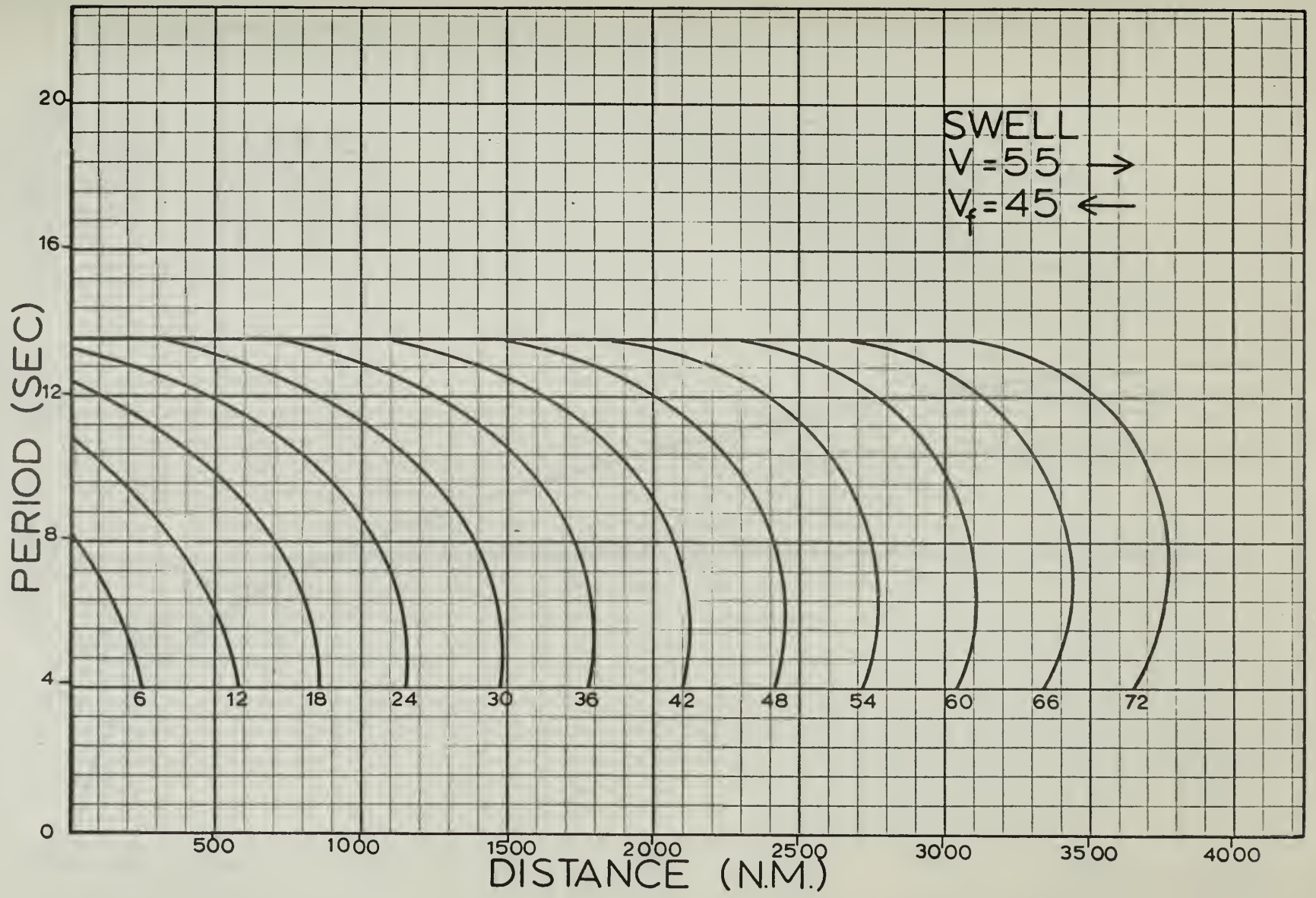



SWELL
V = 55 →
V_f = 40 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE (N.M.)

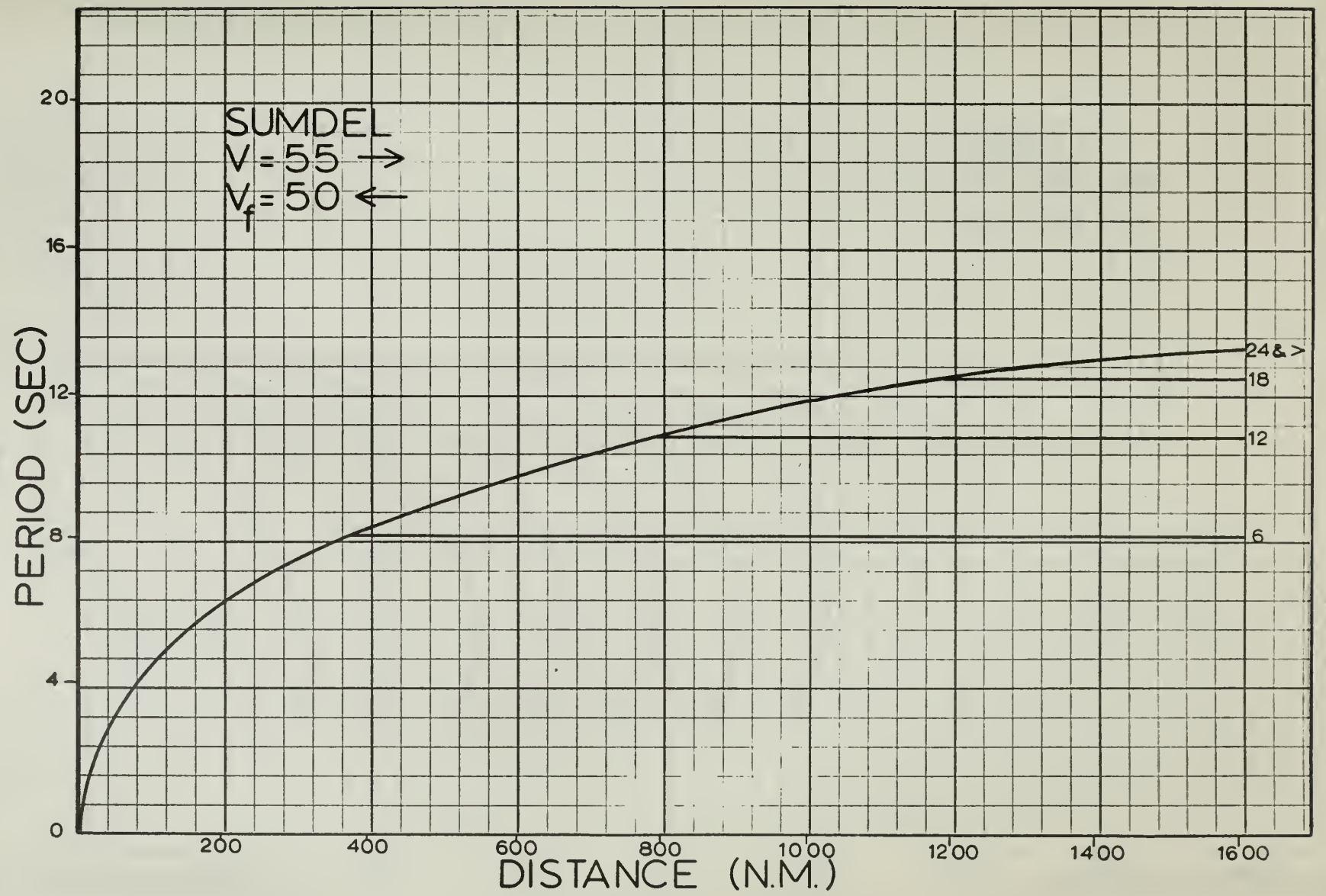



SUMDEL
V = 55 →
V_f = 45 ←
PERIOD (SEC)
0
4
8
12
16
20
DISTANCE (N.M.)
200
400
600
800
1000
1200
1400
1600
24&>
18
12
6

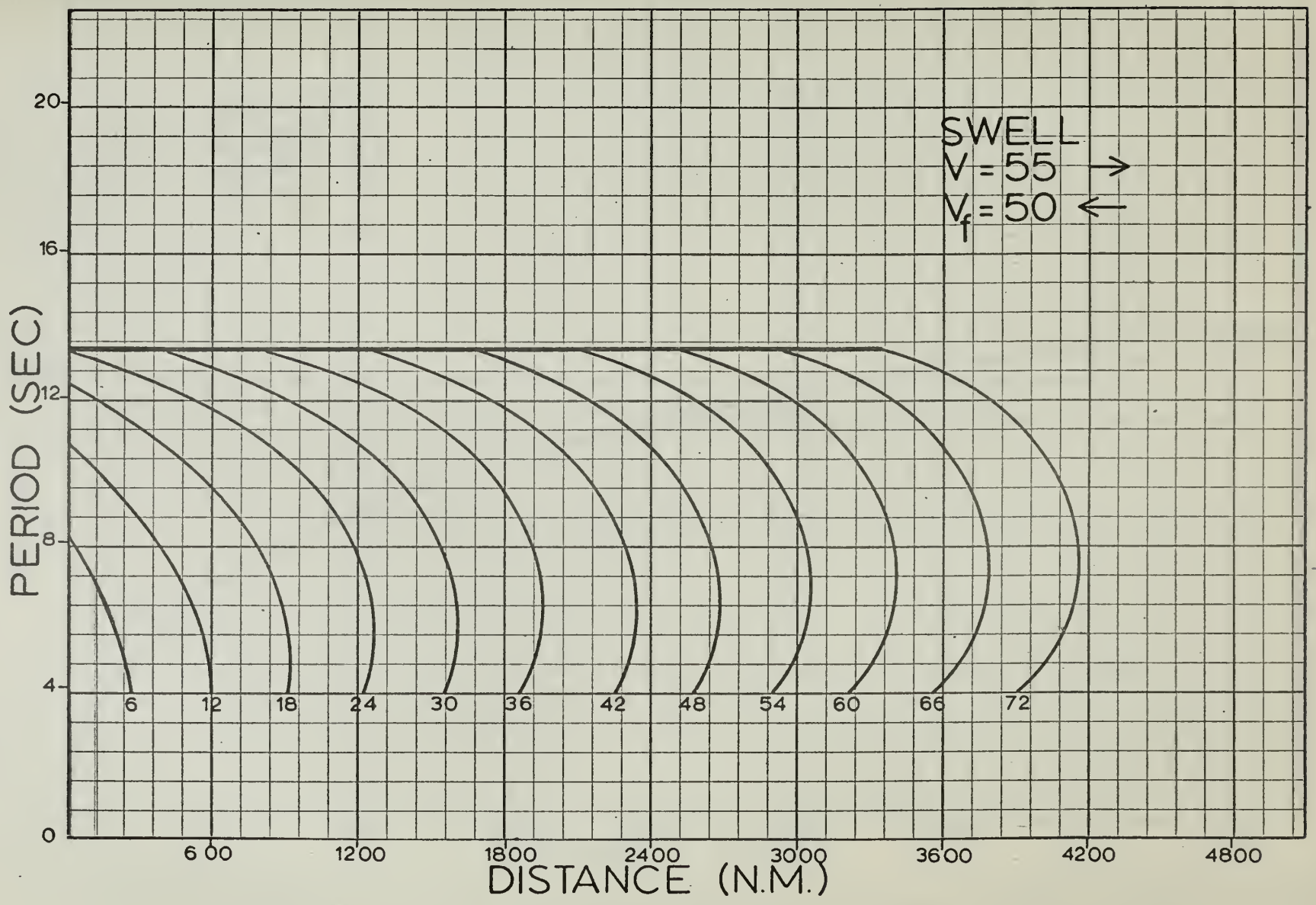



SWELL
V = 55 →
V_f = 45 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE (N.M.)

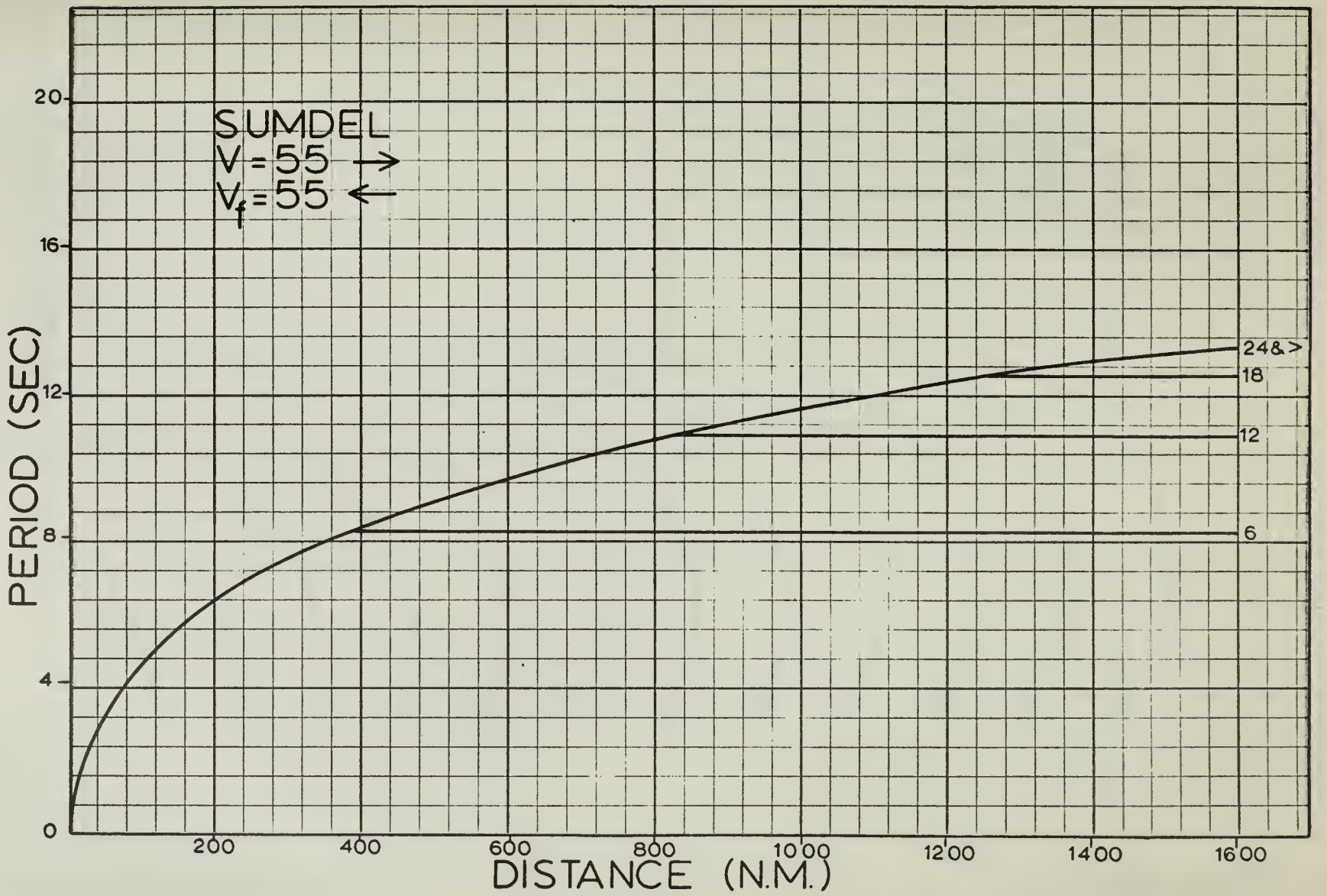



SUMDEL
V = 55 →
V_f = 50 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
24 & >
18
12
6

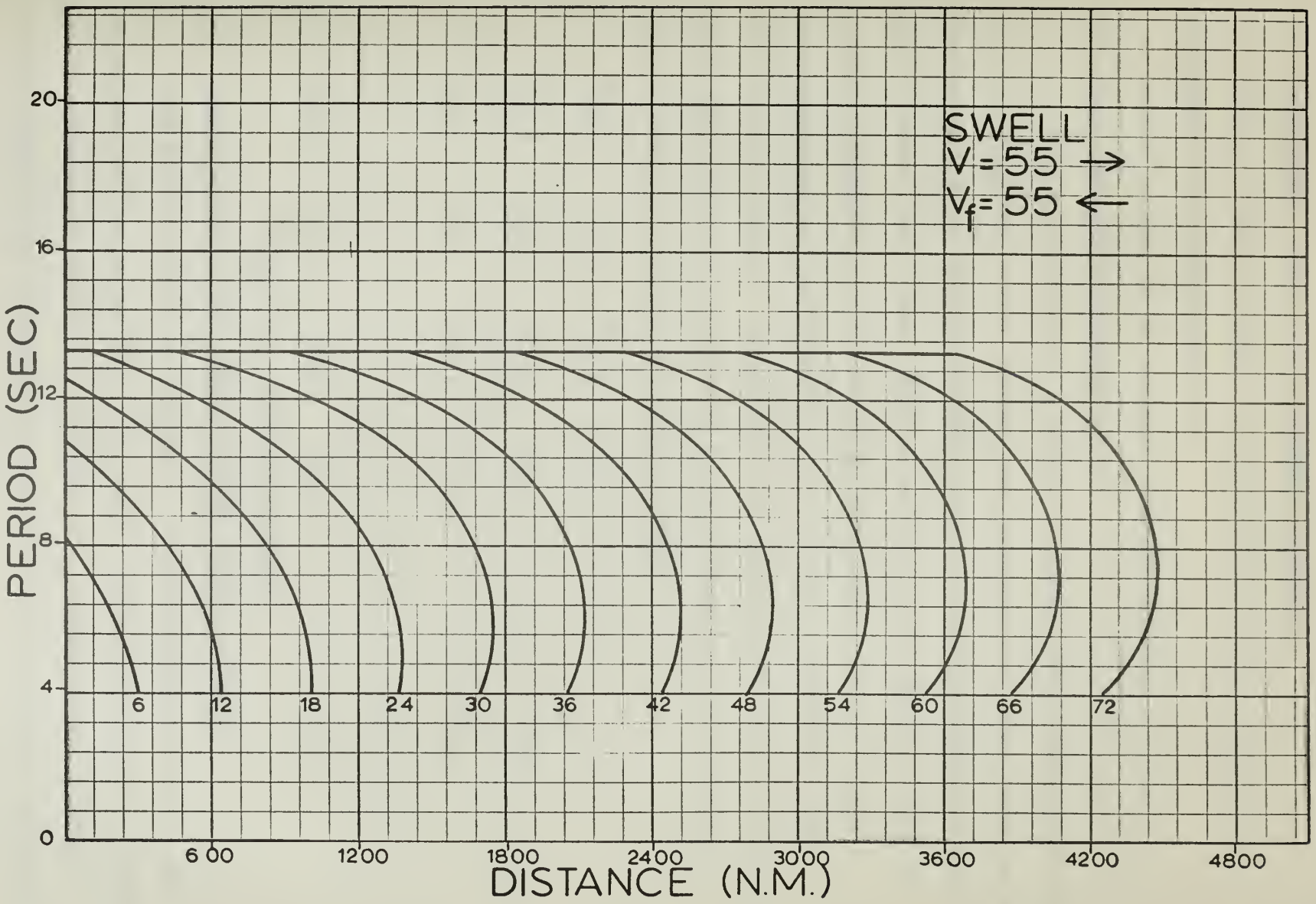



SWELL
V = 55 →
Vf = 50 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
600
1200
1800
2400
3000
3600
4200
4800
DISTANCE (N.M.)




SUMDEL
V = 55 →
Vf = 55 ←
PERIOD (SEC)
0
4
8
12
16
20
200
400
600
800
1000
1200
1400
1600
DISTANCE (N.M.)
24&>
18
12
6




SWELL
V = 55 →
Vf = 55 ←
PERIOD (SEC)
0
4
8
12
16
20
6
12
18
24
30
36
42
48
54
60
66
72
600
1200
1800
2400
3000
3600
4200
4800
DISTANCE (N.M.)



APPENDIX A

1. Programming, Computing and Graphing Procedures

Fortran computer language utilizing the Control Data Corporation 1604 computer was used exclusively.

A brief outline of the procedure employed follows.

1.1 The Co-Cumulative Spectrum arrays

In order to have a table of values of maximum period and minimum required fetch as functions of wind velocity and generation time, the Co-Cumulative Spectra of Pierson, Neumann and James were read into the program as fifty-five by seventy-two arrays. That is, periods and Fo' were read into the computer memory for each five knots of wind from fifteen to fifty-five knots and every two hours duration time from two to seventy-two hours. Fig. A-1 is a schematic representation of this array for period, $T(V,t_d)$; where (V) is the wind velocity and t_d is the duration. A similar array for Fo' was also read into the computer memory.

$$\begin{array}{cccccc}
T_{15,2} & T_{15,4} & T_{15,6} & T_{15,8} & \cdots\cdots & T_{15,72} \\
T_{20,2} & T_{20,4} & T_{20,6} & T_{20,8} & \cdots\cdots & T_{20,72} \\
T_{25,2} & T_{25,4} & T_{25,6} & T_{25,8} & \cdots\cdots & T_{25,72} \\
\vdots & \vdots & \vdots & \vdots & & \vdots \\
T_{55,2} & T_{55,4} & T_{55,6} & T_{55,8} & \cdots\cdots & T_{55,72}
\end{array}$$

Figure A-1. Wave Period Array.

1.2 Computations for LAG, SWELL, FOPRIME, SUMDEL or SWEDEL

Each model required the writing of a separate program utilizing the equations outlined in Sections 5, 6, and 7. Since the programs are unique to this thesis and would be of interest only to those readers wishing to pursue further study of these methods, they are not included. They may be

obtained by contacting the authors through the thesis advisor at the U. S. Naval Postgraduate School, Monterey, California.

1.3 All condition print-out

In order to check the validity of the computations, the programs for each of the three situations were run for the nine values of fetch velocity, fifteen to fifty-five knots, with the wind velocity ranging from the specified fetch velocity up to and including fifty-five knots. When the validity of the computations was verified by random hand analysis, these computed values were then used to set the scaling factor for the proposed graphs of the four variables (LAG, SWELL, FOPRIME and SUMDEL).

1.4 Modification of the Program

Two modifications were necessary in order to use the all-purpose program in the computations required and its adaptation to a graphical output. The first step was the addition of the "call graph" statements. These statements called into the program the subroutine GRAPH.

1.5 The Production Run

For each situation the programs were run for the nine fetch velocities. Each run resulted in a tabulated output (an example of which is enclosed as Fig. A-2) and a graph-output tape. The graph-output tape was then run on the CDC 160 computer in conjunction with the CALCOMP Graph Plotter, utilizing the graph-plot program.

WIND VEL	FTCH VEL	OB TIME	DURATION	PERIOD	SUMDELD	LAG	LEAD	FOPRIME
40	15	6	2	4.3	16	33	0	0
40	15	6	4	6.0	28	11	0	0
40	15	6	6	7.1	37	0	0	0

WIND VEL	FTCH VEL	OB TIME	DURATION	PERIOD	SUMDELD	LAG	LEAD	FOPRIME
40	15	12	2	4.3	16	84	0	0
40	15	12	4	6.0	28	47	0	0
40	15	12	6	7.1	37	25	0	0
40	15	12	8	7.6	44	13	0	0
40	15	12	10	8.2	49	5	0	0
40	15	12	12	9.1	51	0	0	0

WIND VEL	FTCH VEL	OB TIME	DURATION	PERIOD	SUMDELD	LAG	LEAD	FOPRIME
40	15	18	2	4.3	16	135	0	0
40	15	18	4	6.0	28	82	0	0
40	15	18	6	7.1	37	50	0	0
40	15	18	8	7.6	44	34	0	0
40	15	18	10	8.2	49	20	0	0
40	15	18	12	9.1	51	7	0	0
40	15	18	14	9.6	52	1	0	0
40	15	18	16	10.1	52	0	0	170
40	15	18	18	10.5	50	0	0	230

WIND VEL	FTCH VEL	OB TIME	DURATION	PERIOD	SUMDELD	LAG	LEAD	FOPRIME
40	15	24	2	4.3		186	0	0
40	15	24	4	6.0		118	0	0
40	15	24	6	7.1	37	76	0	0
40	15	24	8	7.6	44	55	0	0
40	15	24	10	8.2	49	36	0	0
40	15	24	12	9.1	51	14	0	0
40	15	24	14	9.6	52	4	0	0
40	15	24	16	10.1	52	0	70	80
40	15	24	18	10.5	50	0	45	140
40	15	24	20	11.1	46	0	20	205

Figure A-2. Tabulated Computer Output.

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1. New York University, School of Engineering and Science, Research Division. Estimates of the power spectra for fully developed seas for wind speeds of 20 to 40 knots, by Lionel Moskowitz. September, 1963. Department of Meteorology and Oceanography Geophysical Sciences Laboratory Report No. 63-11.

2. New York University, School of Engineering and Science, Research Division. A proposed spectral form for fully developed wind seas based on the similarity theory of S. A. Kitaigorodskii, by Willard J. Pierson, Jr. and Lionel Moskowitz. October, 1963. Department of Meteorology and Oceanography Geophysical Sciences Laboratory Report 63-12.

3. Pierson, W. J. Jr., G. Neumann, R. W. James: Practical Methods for Observing and Forecasting Ocean Waves by means of Wave Spectra and Statistics. H. O. Pub. No. 603; 1955.

Simplified spectral forecasts of sea and
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